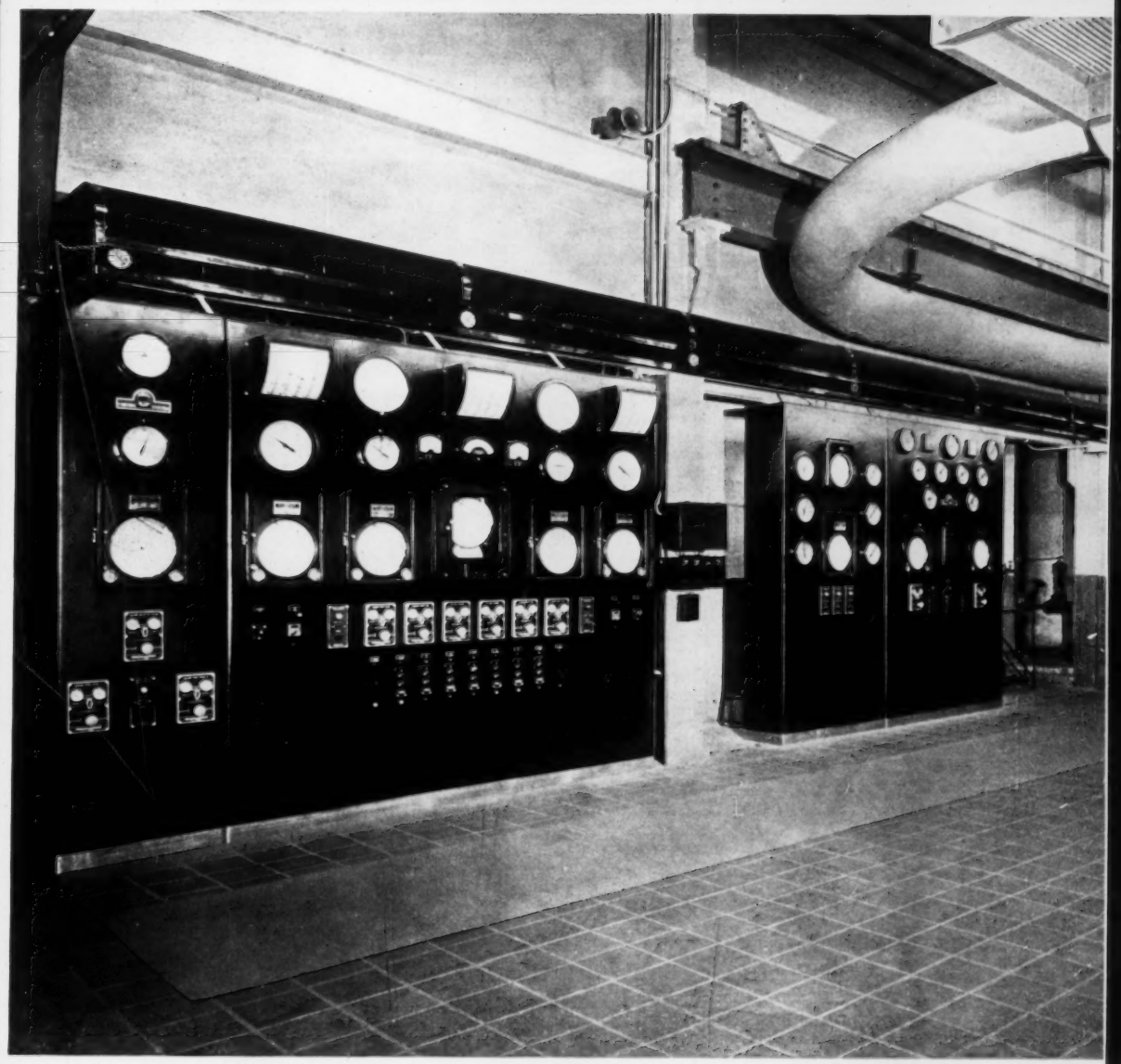
THE MAGAZINE OF

MEASUREMENT and CONTROL

INSTRUMENTS



BOILER CONTROL, ROCHESTER GAS & ELECTRIC CORP., ROCHESTER, N. Y.
Courtesy Bailey Meter Co.

INSTRUMENTS AND METHODS FOR

MEASURING DRIVING SKILL

See page 109

VOLUME 9
APR.
1936
NUMBER 4

"NOTHING ELSE IS LIKE IT!"

"The New-Series Foxboro Potentiometer Recorder Offers an Extra Compensating Slide Wire"

This original Foxboro development means *uniform sensitivity at all points on the scale!* A given deflection of the galvanometer pointer results in the same amount of pen movement whether the pen is at the low, middle or high point on the chart. Only the improved Foxboro Potentiometer Recorder offers this advantage—nothing else is like it. Yet it's only *one* of the many improvements you'll find in this new series of pyrometers. New Bulletin 190-1 illustrates and describes them completely —*send for your copy.*

THE FOXBORO COMPANY
46 Neponset Avenue
FOXBORO, MASS., U. S. A.

Branch Offices in 20 Principal Cities

POTENTIOMETERS
Indicating
Recording
Controlling

MILLIVOLTMETERS
Indicating
Recording

ELECTRIC RESISTANCE THERMOMETERS
Indicating
Recording
Controlling

FOXBORO
REG. U.S. PAT. OFF.
PYROMETERS

• COMPLETE INDUSTRIAL INSTRUMENTATION •

MORE SPEED!

INTO THIS ERA of streamline travel, industry and life comes another contribution to speed—GREATER SPEED IN ACCURATE MEASUREMENT, CONTROL OF TEMPERATURE.

NEW *Taylor* THERMOSPEED

the fastest thing in separable well tube systems known today

SPEED up sluggish response to temperature changes! Greatly reduce delayed valve action and control where separable wells are needed!

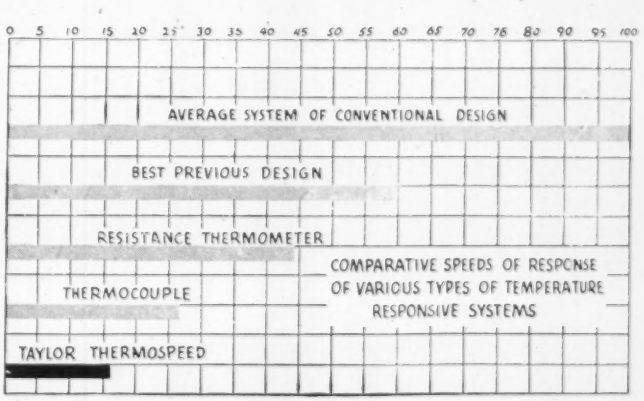
Taylor brings new speed of response to separable well tube systems. Taylor engineers contribute another new development in temperature recording and control . . . a development that is six times faster than the average separable well system now in service. TAYLOR THERMOSPEED IS ITS NAME.

A new design of unusual originality and effectiveness in bulb and separable well construction keeps up with rapid temperature changes at the bulb. It enables Taylor Recording Thermometers to show a truer and more accurate picture of temperature at the bulb. It causes control valve corrections to be made at the slightest tendency to depart from the control point. Taylor-Controllers give closer regulation.

THIS IS IMPORTANT. Taylor Recording and Controlling Instruments, with all their refinements and improvements—outstanding instruments in their accuracy, efficiency and durability—can now operate with greater speed and precision than ever before in connection with separable well tube systems.

BULB CONDUCTION ERROR REDUCED. The Taylor Thermospeed construction makes another important contribution to thermometer accuracy and speed of response. Changes in the temperature of the bulb mounting or of the supporting wall have a negligible effect on the bulb temperature. This variation, known as BULB CONDUCTION ERROR, is reduced to a minimum. The comparative conduction error of separable well instruments is shown in the graph.

If you use separable well tube systems, get the information about the new Taylor Thermospeed construction. You will see results quickly—in better temperature control . . . and more efficient and economical control of your production of finished goods. Ask a Taylor Representative or drop a line at once to Taylor Instrument Companies, Rochester, N. Y., or Toronto, Canada. Manufacturers in Great Britain—Short & Mason, Ltd., London, England.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AVERAGE SYSTEM OF CONVENTIONAL DESIGN
BEST PREVIOUS DESIGN
RESISTANCE THERMOMETER
THERMOCOUPLE
TAYLOR THERMOSPEED
COMPARATIVE SPEEDS OF RESPONSE OF VARIOUS TYPES OF TEMPERATURE RESPONSIVE SYSTEMS

THIS GRAPH shows comparative speeds of response of various types of temperature responsive systems plotted to an arbitrary scale. The comparisons were made with bulbs in standard wells and in a thoroughly agitated water bath.

With the time of response for a conventional tube system as 100, the Taylor "Thermospeed" responds to the same temperature change in only 1/6 of the time. Note the superior speed of response of the "Thermospeed" System as compared to a thermocouple and a resistance thermometer of good design.

Taylor

Indicating Recording Controlling

TEMPERATURE, PRESSURE *and* **FLOW INSTRUMENTS**

INSTRUMENTS The Magazine of MEASUREMENT and CONTROL

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Courtesy Bailey Meter Co.

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INSTRUMENTS The Magazine of MEASUREMENT and CONTROL

M. F. BEHAR
EDITOR

IN THIS ISSUE

Fortunate coincidences have played no small part in making possible the completeness (sometimes the very appearance) of many articles. First noticed in 1930, this phenomenon manifested itself almost sensationally in '34 and '35, compelling us to recognize it as a definite factor contributing to the success of our editorial efforts. We tested its dependence on secrecy by bragging about it in print: better and more frequent "strokes of luck" followed. The day before the flood, some "hunch" made us bring upstairs all unpublished manuscripts of which there were no carbon copies. Other fortunate coincidences are evident in this issue: When we interviewed Subscribers L. V. Black and W. R. Gray (see page 92) we did not know that they were graduates of instrument-company training courses. Black told us he attended a B & L course—the very one of which we had published a group photograph in our November 1935 issue. Gray told us he attended the Brown Instrument Co.'s course—and that same day we received an article describing that course (see page 109). Last summer we made a wish that in April of this year (when the driving season begins) we could publish an article on how instruments can reduce bad driving, and Professor DeSilva recently sent us the best article on this subject ever submitted to any magazine (see pages 100-108). As for Perry Borden and Ralph Batcher, their stores of experience regularly gratify our most exacting unuttered wishes.

THE FRONT COVER

Taken in the boiler-turbine room at the Rochester Gas and Electric Corp.'s Plant No. 3, Rochester, N. Y., it shows Bailey meters and air-operated control for the automatic operation of a 250,000-lb./hr. pulverized-coal-fired boiler: complete combustion control, 3-element feed water control, feed water pump control, desuperheat control, and pressure reducing control.

ERRATA

The March issue you received was printed from flood-damaged forms which, in spite of our printer's efforts, loosened every now and then. On page 87, the top and bottom lines of the second and third columns are transposed; also the second line of the second column should be the sixth. Illustrations did not look so bad, considering that >100 cuts had to be reblocked, straightened or made over!

FIRST of all, from the bottom of our heart, we thank all those kind friends who sent expressions of sympathy to the Instruments Publishing Company or to individual members of the staff. In answer to numerous inquiries we state the facts: Our offices are on the third floor of the Herbick & Held Printing Co.'s establishment—the two buildings at the left in the adjoining photograph.* Dirty waters rose to nearly the ceiling of the ground floor. Our March issue, ready to be taken to the Post Office, was destroyed and had to be reprinted. Most of our property downstairs (cuts, etc.) is being salvaged. We cannot brood over our own losses when we think of those suffered by the industries and residents all around this building and in other flooded areas.

Courage, unselfishness, prompt action and resourcefulness were displayed during and after the flood; they were aided by instruments of numerous types, especially insulation-testers such as the one in this Westinghouse photograph. And we can't refrain from pointing out that if automatic radio-telemetric gages had been installed along the Allegheny and Monongahela Rivers the Weather Bureau would have been able to extrapolate the curve and predict the 46-ft. crest, so that many lives and millions of dollars' worth of property could have been saved in this district by reason of definite warning.

*Taken by Malcolm Lovejoy, proofreader, Herbick & Held Printing Co., when the waters had receded approx. 8 ft. below crest stage.

INSTRUMENTS' READERS AT WORK

No. 6 WILLIAM R. GRAY

Head, Instrument calibration and maintenance

No. 7 LLOYD V. BLACK

Physicist, Research Laboratory

Pittsburgh Plate Glass Co. (Glass Div.), Creighton, Pa.

By M. F. BEHAR

EVERY modern industry is an athletic stadium, the main event being a non-stop race between processing equipment and process control equipment. Each advance in the instrumentation of a process makes possible a better process and leads to improvements in the processing equipment, immediately creating a need for even more highly specialized instruments . . . and so on. The friendlier the race, the faster. Records fall when all runners belong to one team and each one's advance speeds the others. The ideal team line-up includes processing theory, processing equipment design, instrument design and instrument application—each a "double-threat" member (fundamental knowledge and practical experience).

We witnessed such a team at work when we visited the new laboratory building of the Pittsburgh Plate Glass Co. at Creighton, Pa., twenty miles above Pittsburgh on the Allegheny River. This central laboratory serves the eight plants (in Pennsylvania, Ohio, West Virginia and Missouri) where the company's glass products are made. It is an ideal four-*member* team, in the persons of two *men*, W. R. Gray and L. V. Black.

When Gray graduated from high-school the country was at war, and so he joined the Navy. As a First-class Quartermaster he used nautical instruments, so on his discharge he joined the Thwing Instrument Co. In 1923 he went to the Brown Instrument Co. and in 1926 obtained his present position. He speaks highly of the training he received under Dr. Thwing—for whom he has a deep affection—and at the Brown Instrument School. In turn, he has trained the men who under his direction maintain the instruments in the company's eight plants.

Black's acquaintance with instruments likewise began during the war: he was an army aviator. Then he taught science at the Crystal City (Mo.) High School, took his Master's degree at the University of Missouri in 1929 (majoring in physics) and that same year obtained his present position. He, too, attended an instrument company's school—that of Bausch & Lomb—in 1932. He is the author of numerous technical papers, one of which, "Transmission of Radiant Energy Through Glass," made scientific history.

Though not officially a "scientist," Gray has collaborated with Black, especially in fundamental work on insulating values of air spaces between glass, for which research he designed radically new apparatus, including wind direction instruments.

Most of the instruments used in connection with glass manufacture under Gray and Black are of special design and construction, representing perfect team-work on the part of Physicist Black, Instrumentician Gray, and various instrument firms.

These instruments cost half a million dollars but they yield dividends of incalculable value: "Without instruments, our processing equipments couldn't function properly," said one.

"And without *Instruments*, WE couldn't function properly!" added the other.

TABLE I—PRINCIPAL APPLICATIONS

Glass Tanks—(1) Automatic temperature control systems with rare-metal couples all through walls and roof. (2) Optical pyrometers read 3 times daily to check performance of controls.

Glass Furnaces—Same as glass tanks.

Pot Arches—Same as glass tanks.

Lehrs—Pyrometers, plus manual temperature control on old lehrs and full-automatic control on all new lehrs.

Kilns—Thermoelectric pyrometers—millivoltmeters and potentiometers.

Glass Hardening Equipment—Millivoltmeter and potentiometer types of controllers. (Extreme accuracy and stable control essential.)

Warerooms—Automatic control of humidity and temperature.

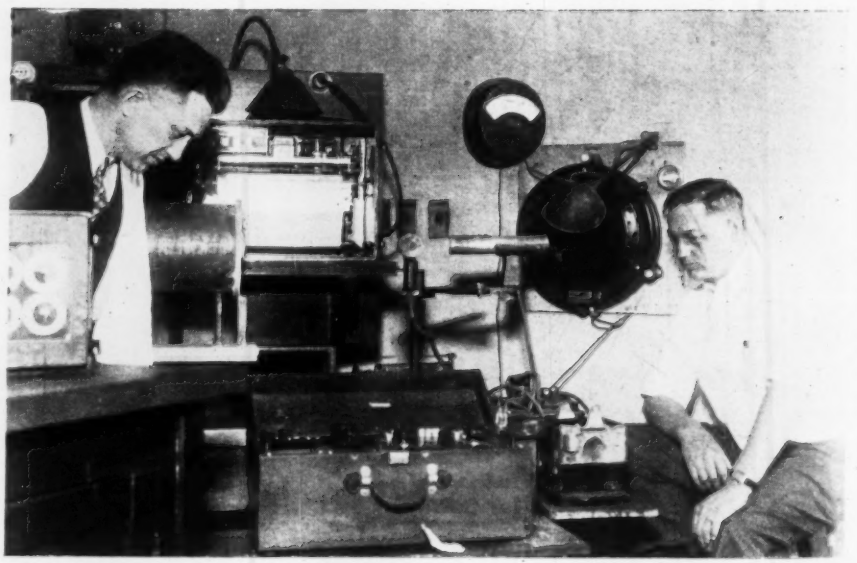
Plate Glass Grinders and Other Machines—Recording and indicating wattmeters and tachometers.

Inspection Lines—Polariscopes, etc.

Experimental Processing Equipments in Laboratory—Every type is reproduced on a small scale and operated with various models of indicating, recording and controlling instruments.

TABLE II—PROCESSING AND TESTING INSTRUMENTS

Optical pyrometers	36
Pyrometric recorders	75
Dial and recording thermometers	200
Temperature control systems	75
Flow meters (indicating, recording, integrating, controlling)	19
Pressure gages (incl. recorders)	700
Vacuum gages (incl. recorders)	100
Tachometers (incl. recorders)	33
Wattmeters (mostly recorders)	250
Standard precision potentiometer	1
Semi-precision potentiometers	8
Portable potentiometers	27
Microscopes	8
Refractometers	4
Polariscopes	6



The periodical calibration of optical pyrometers (which in turn are used to check other instruments) is of supreme importance. Black (left) and Gray do it themselves, using a platinum-wound furnace with precision thermoelectric and potentiometric equipment.

THE MONTH'S NEW INSTRUMENTS

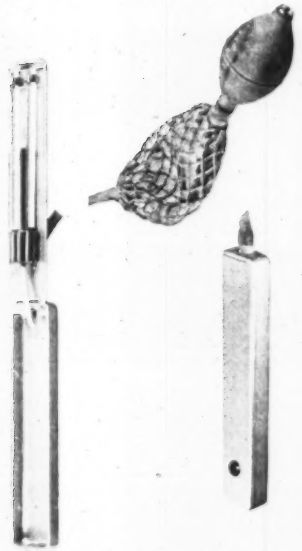
In this department we strive to report each month ALL the new devices for measurement, inspection, testing, metering and automatic control—in the form of concise technical descriptions.

When writing to manufacturers directly, please mention this department as your source of information.

Or write to Information Section, Instruments Publishing Company.

Hand-Aspirated Psychrometer

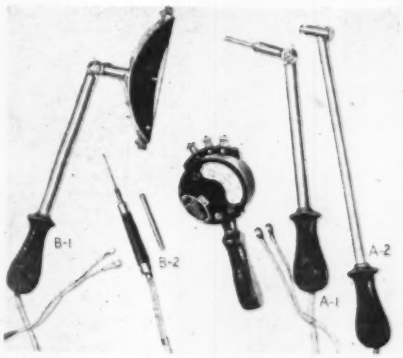
Air is drawn across wet and dry bulbs at uniform high velocity. Hand pump forces air through a Venturi tube, inducing secondary air from the outside.



Cover of small chamber in which bulbs are enclosed may be opened to facilitate applying water to wet-bulb, and thermally shields bulbs. Thermometers are secured to the hinged lid; and case serves as an adequate handle when instrument is in use. Operation being simple, accurate results can be obtained by a person unskilled in use of sling psychrometer.—*Julien P. Friez & Sons, Inc., Baltimore, Md.*

Combination Surface and Needle Pyrometers

New "universal set" thermoelectric pyrometer comprises one handled indicator and four different forms of interchangeable surface and needle elements:



"A-1" is for molds and other applications where temperature of small surface must be measured, "A-2" is for flat surfaces in general, "B-1" is for surface temperatures of stationary or moving rolls, "B-2" is particularly useful for measuring inside temperatures of materials in plastic state, is equipped with protective cover. Indicator is scaled 30-1000°F.—*The Pyrometer Instrument Co., 103 Lafayette St., New York City.*

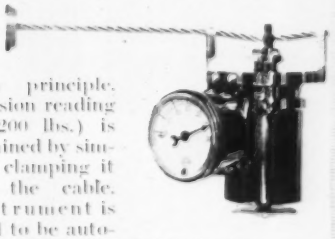
Portable Thermometer

Illustration shows improvement made in design of this type of recording thermometer: mercury-filled bulb is located where it is subjected to natural air cur-

rents. Accuracy is higher because circulation permits bulb to attain temperature of air, not of case. Lag is greatly reduced because bulb can follow changes, whereas if it were within instrument case or mounted close thereto for its entire length, it would be affected by case temperature which, by reason of relatively large mass of metal, lags considerably. New instrument is built for rough service, has 8" 24-hr. chart.—*The Brown Instrument Co., 4482 Wayne Ave., Philadelphia, Pa.*

Shunt Type Cable Tension Indicator

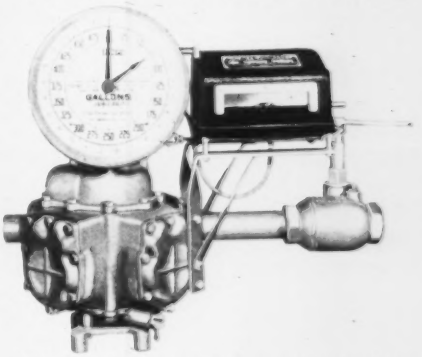
Measurement and equalization of tension on small cables (< 3/16" diam.) can now be accomplished through the use of this small new device, operating on the deflec-



tion principle. Tension reading (<200 lbs.) is obtained by simply clamping it on the cable. Instrument is said to be automatically adjusted for temperature changes, requires no special bushings for cables of different sizes.—*Martin-Decker Corp., Long Beach, Calif.*

Predetermining Valve and Printing Device for Liquid Meter

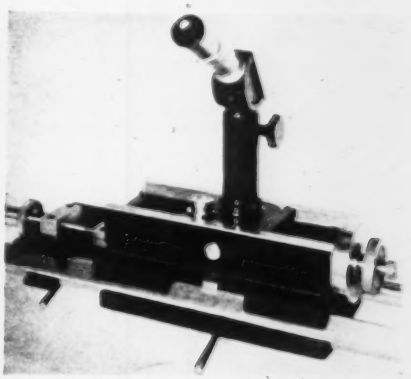
For automatic shut-off of liquid flowing through a meter after any determined amount has been measured, the Pittsburgh Predetermining Valve enables the operator of the meter to set the register for any predetermined quantity. It can be furnished with any



Pittsburgh four-cylinder reciprocating piston type meter (see *Instruments*, Jan. 1933, pages 14-15) for oil, gasoline, industrial solvents, beer, etc. These meters may also be equipped with the Pittsburgh Meter Duplicator, another new development. This instrument prints a receipt in duplicate of the amount of liquid that has passed through the meter. Registers can be furnished either of the vertical setback type, as illustrated, or of the straight-reading horizontal setback type.—*Pittsburgh Equitable Meter Company, 700 N. Lexington St., Pittsburgh, Pa.*

Dendroheliconometer

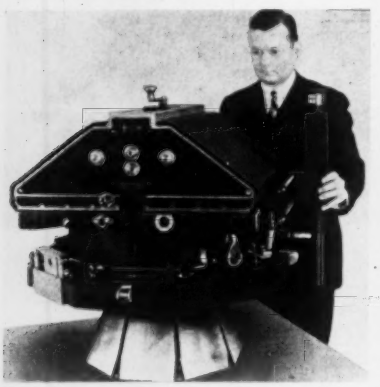
Designed for the study and comparison of growth ring structures of trees. Consists of a precision micrometer slide of 100-mm. range, carrying a reading microscope and mounted with a carriage on an optical bench. Micrometer slide



drum permits reading directly to 0.01 mm. and easy estimating to 0.002 mm. Carriage is provided with a clamp and with an index to read its position on bench. Microscope has interchangeable objectives and eyepieces, and a variable tube length to provide any magnification from 5 to 10 diameters.—*Gaertner Scientific Corp., 1201 Wrightwood Ave., Chicago, Ill.*

Aerial Mapping Camera

This nine-lens aerial camera just completed for the U. S. Coast and Geodetic Survey is said to be the largest single-unit aerial mapping camera ever built.



It weighs 305 lbs. loaded, stands <36" high, has a record focal length for a multi-lens aerial camera of 8½", photographs an area of 600 sq. miles at one exposure from an altitude of 30,000 ft. and is fully automatic. The telescopic view finder on the side includes a drift indicator and automatic overlap control. Eight steel mirrors, one for each of the side lenses, are mounted vertically and spaced equidistantly around the single center lens. They are coated with sputtered aluminum to increase reflectivity from 60 to 80%. The images from the nine lenses are photographed on one film, which has a negative size of 23"x23", instead of an individual film for each lens as with other multi-lens aerial cameras. The film is 200 ft. long, sufficient for 100 exposures at one loading.—*Fairchild Aviation Corp., 62-10 Woodside Ave., Woodside, L. I., N. Y.*

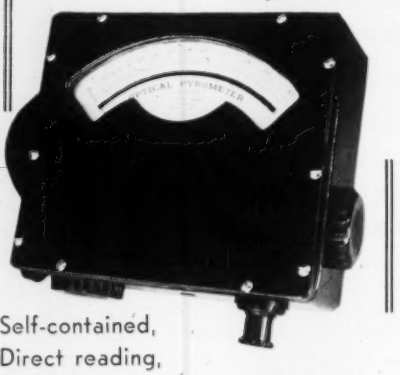
"Motoscope C"

Feature of this automotive vehicle engine analyzer is a coil tester said to be based upon an entirely new and different principle: it consists of a cam driven

at constant speed by a 110-volt motor, and a time control for heating the coil up to operating temperature, thus reproducing conditions encountered in actual use. Analyzer permits testing battery voltage, starter load, starter lock load draw, low tension distributor supply, condenser, coil, spark plugs, points, distributor, high tension wires, magnetos, carburetors, valves, timing of valves and ignition, leaky gaskets, choke, valve springs, booster brake, fuel pump, vacuum tank and compression.—*Stromberg Motoscope Corp., 2150 Lawrence Ave., Chicago, Ill.*

PRECISION
Portable
Potentiometers
Pyrometers

Model B Optical Pyrometer

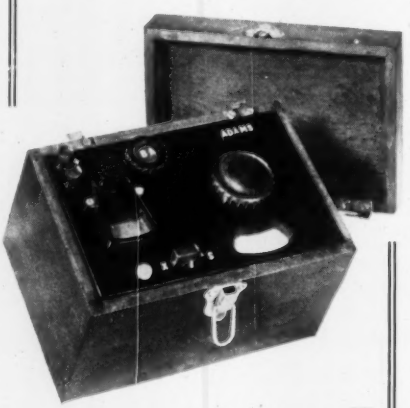


Self-contained,
Direct reading,
Eliminates suppressed-zero-ammeter.
Each instrument hand-calibrated against standard.

MODEL B-1
Single Range ..... 1500-3000°F.

MODEL B-2
Double Range ..... 1400-2500°F. / 2200-3800°F.

Model B Potentiometer



Compact, durable, self-contained and of high precision. Ranges cover all applications. Calibrated directly in Temperature, pH, etc., or in millivolts.

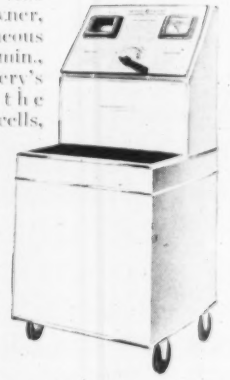
Eastern Distributors
Eimer & Amend
New York

Western Distributors
Claude S. Gordon
Chicago Cleveland
Indianapolis

HURL R. ADAMS
Alhambra Way Pittsburgh, Pa.

Photometric Battery Tester

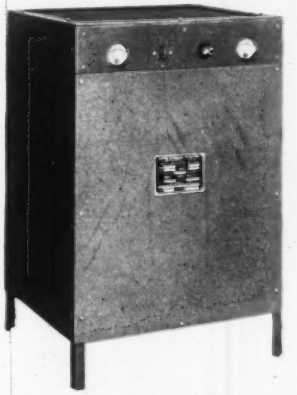
A new "Tungar" battery tester, utilizing a photometric method of indicating the battery's cell-condition and featuring a system of simplified "readings" easily understood by the average car-owner, affords simultaneous testing in <1 min., of both the battery's capacity and the condition of its cells, and can also be used to determine the working capacity of an old battery in terms of the number of plates of an equivalent "good" battery. It embodies two instruments:



One is used for the capacity test, and its pointer traverses a scale reading "Good," "Fair," and "Replace." The other depicts cell-condition photometrically: it has a face on which appears the outline of a miniature 3-cell battery. Behind each "cell" is a lamp operated by the corresponding cell of the battery on test. If one light-field is visibly darker than the others, a defective cell is indicated. Similarly, attention is called to a shorted cell. If the light-fields are uniform but dim, the battery needs recharging. Sensitivity is 0.2 volt. The new tester has a special rheostat which assures correct high-rate discharge in testing for "capacity": instead of setting the rheostat control handle for actual number of plates, it is set for any smaller number which will result in a "good" reading, so that the working capacity of an old battery in terms of the number of plates of an equivalent "good" battery is obtained. The spot-welded steel truck is finished in bright-red enamel with chrome and black trim, in order to attract motorists' attention.—*General Electric Co., Appliance & Merchandise Dep't, Bridgeport, Conn.*

Controlled Rectifiers

To provide d-c. power from an a-c. power supply for small public and private telephone systems, these new "Bulletin 8602" controlled rectifiers on an



a-c. line varying ± 10% supply a d-c. voltage maintained constant to ± 1½ volt from no load to full load. These rectifiers are designed for 60-cycle, 3-phase, 208-220-240 nominal line volts input and for 50 ± 1½ volt, 5- and 10-amp. outputs.—*Ward Leonard Electric Co., 31 South Street, Mt. Vernon, N. Y.*

BAILEY METER CONTROL SYSTEM

The Mark of

Effective Control

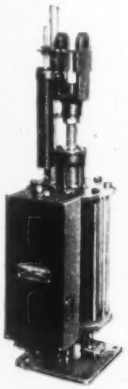
Process Control for sensitive, stable automatic control of temperature, pressure, liquid level, flow and other factors as applied to industrial processes. Responds to changes quickly, without overtravel or hunting. Ask for Bulletin No. 101.

Combustion Control that is simple but *complete* for providing economical operation of boilers of 200 h. p. and larger. Details in Bulletin No. 102.

Recorder-Controller

Boiler Meters for recording combustion conditions and guiding boiler operators. Described in Bulletin No. 44.

Multi-Pointer Gages for indicating factors such as draft, pressure, temperature and speed. These Gages are available with any number of pointers and any scale combination; in either the oil sealed bell or diaphragm construction.



Control Drive

Flow Meters for indicating, recording and integrating the flow of steam, water, sewage, air, gas and other fluids. Bulletins No. 39 and 300.

Recorders for pressure, temperature, drafts, liquid level and other factors.

G-3

BAILEY METER COMPANY

1041 Ivanhoe Rd., Cleveland, Ohio

Electric Tachometers

Two d-c. tachometric magnetos are announced which, in connection with maker's industrial d-c. recording potentiometers, provide a variety of combina-

Fig. 1

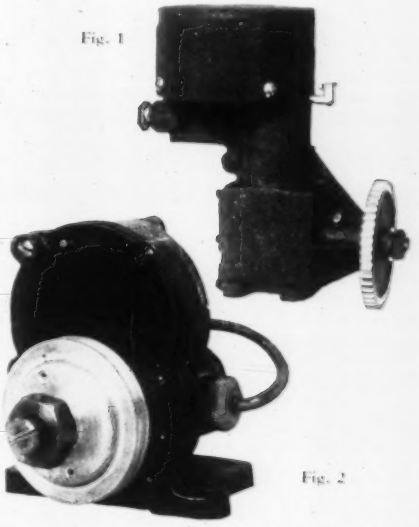
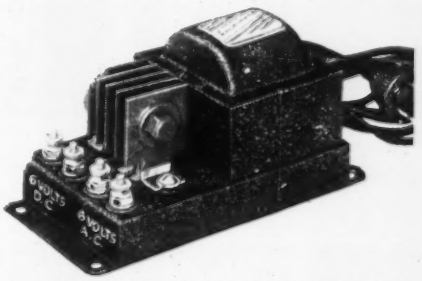


Fig. 2

tions for plant and laboratory speed-measuring applications. Fig. 1 shows heavy-duty vertical-shaft model. Its field is furnished by a one-piece, heavy-section, tungsten steel magnet, cadmium-plated against corrosion. Commutators and brushes are of gold alloys, to give constant, uniform brush pressure and parallelism. Vertically mounted shaft prevents lubricant from reaching commutator. Bevel gear box for horizontal drive. Oiling required once a year; all working parts readily accessible. Mounted in splash-proof case. Fig. 2 shows the light-duty horizontal-shaft model, designed for intermittent runs: dynamometers, test stands, laboratory work, and light production. Each magneto generates an emf., directly proportional to speed, which is balanced against a known emf. in the potentiometric recorder, which may be either the standard strip-chart model with automatic standardizer or the round-chart model with "giant dial" indicating feature. Either recorder may be fitted with contacts for signaling or for automatic control.—*Leeds & Northrup Co., 4955 Stenton Ave., Philadelphia, Pa.*

Rectifier and Transformer

"Pow-R-Unit" is said to be only small commercially-available device which supplies two low-voltage currents—one d.c. for solenoids, etc., and one



a.c. for light circuits of application. Measures 3"x5" and weighs 3½ lbs. Two models: 35-watt, supplying 6-volt a.c. and 8-volt d.c.; 25-watt supplying 6-volt a.c. and 6-volt d.c. Both plug into commercial a.c. supply.—*Jefferson Electric Co., Bellwood, Ill.*

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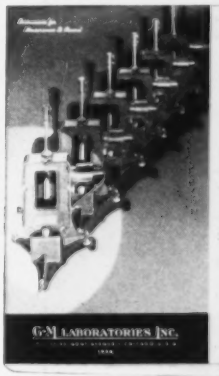
NEW CATALOG



LABORATORY INSTRUMENTS

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SLIDE WIRE RHEOSTATS
D'ARSONVAL GALVANOMETERS
D.C. POWER SUPPLY UNITS
(6 to 3500 Volt Units)

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PHOTOTUBES
PHOTOTUBE RELAYS
SUPER-SENSITIVE D'ARSONVAL RELAYS
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(Control capacity up to 10 amps.)
TAUT SUSPENSION GALVANOMETERS
ILLUMINATION CONTROL EQUIPMENT
(Sensitivity ¼ foot candle)
RHEOSTATS—SLIDE WIRE

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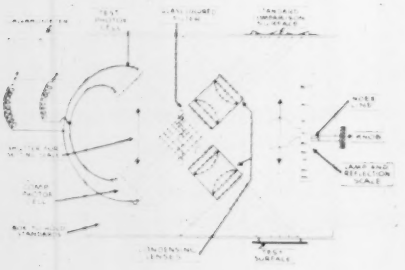
Photoelectric Reflectometer

This new reflectometer, which measures the reflectance, opacity and color of paints, papers, pigments, powders, ceramic products, textiles and chemicals, is a photoelectric adaptation of the Hunter Visual Reflectometer (*Instruments*, Oct. 1934, page 219). Illustration brings out the null method which makes it possible to operate directly from ordi-



nary current supply. Test surface and comparison surface, at opposite ends of a light tunnel, are illuminated by a single lamp movable between them. Each of two rectifier-type photocells receives light reflected at an average of 45° from one of the surfaces. A galvanometer indicates unbalance of cell outputs. The reflectance scale moves with the lamp past a stationary indicator. To determine reflectances, a standard is first placed in the test end of the instrument and the lamp moved to the position for which the scale reading gives the reflectance value of the standard. By means of a compensating shutter, the light falling on one or the other of the photocells is then reduced until the galvanometer reads zero. With instrument thus adjusted, unknown surfaces may be substituted for the standard and their reflectances measured directly. To obtain color values, reflectances in colored light are determined.—*Henry A. Gardner Laboratory, 1201 New York Ave., N.W., Washington, D. C.*

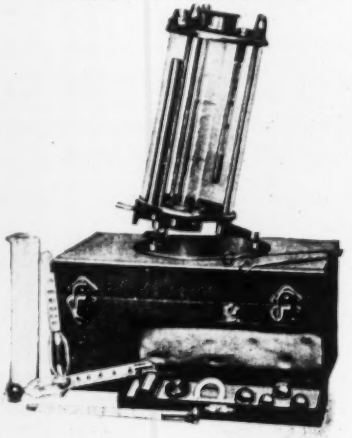
Remote Valve Control

Certain processes are so stabilized by automatic controllers that many non-critical flows may be governed by hand valves which seldom need readjustment. However, if these hand valves are inaccessible, even the few necessary adjustments will be neglected. Where these conditions exist this new device enables the operator to adjust manually an inaccessible valve without moving from his station. A feature is said to be precision of valve setting. The valve opening can be altered by <0.01". Used in conjunction with a Stabilflo valve, the controlled flow can be changed by <1%. Due to design, there is no pumping or vibrating; air pressure on the diaphragm is held at desired setting. Finish: lacquered cast bronze trimmed with buff nickel.—*The Foxboro Co., 26 Neponset Ave., Foxboro, Mass.*

● HÖPPLER VISCOSIMETER

For Determining the ABSOLUTE Viscosity of Gases, Oils, Fluids, Viscous Tars or Syrups, According to the

FALLING BALL PRINCIPLE



Direct Readings in Centipoises (or Centistokes). Only Small Sample (30 cc) Required

RESULTS CONSISTENT AND REPRODUCIBLE

Range: From 0.01 to Over 1,000,000 Centipoises

Accuracy: ±0.1% Between 10 and 600 Centipoises
±0.27% at Extreme Ranges

With Use of Ultra Thermostat Error Can be Reduced to ±0.05% Over Entire Range of Viscosimeter

Difference in Viscosity Between Distilled and Tap Water Can Even Be Measured

When Requesting Detailed Information, State Range of Measurements Required

The above Höppler Viscosimeter was made possible by the use of

Schott & Gen. Jena

JENA KPG PRECISION-BORE TUBING

Bore exact within — .001 mm. (.00025 in.) Smallest bore .5mm., largest bore 50.0mm. Length, except for extreme bores, up to 1 meter. Inside surface is clear like regular transparent glass tubing.

Jena KPG Precision Bore Tubing is a product of the
JENA GLASS WORKS OF SCHOTT & GEN.

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230 East 45th Street, New York, N. Y.

Lathe Instrumentation

Applicable to maker's mechanical or hydraulic "Carbo Lathe," this new head forms a central control, in operator's line of vision, for entire electrical and

pressure systems including: (1) Starting and stopping buttons for all motors; (2) Pressure gages for either air or hydraulic pressure; (3) Ammeters indicating power being consumed, enabling operator to maintain proper speeds and feeds, and warning operator of any electrical trouble before it becomes serious. With this "Electrical Head" the department supervisor can check operator and machine at a glance, thus preventing excessive tool breakage costs a major problem in departments operated on a piece price or premium basis.—*Porter-Cable Machine Co., Syracuse, N. Y.*

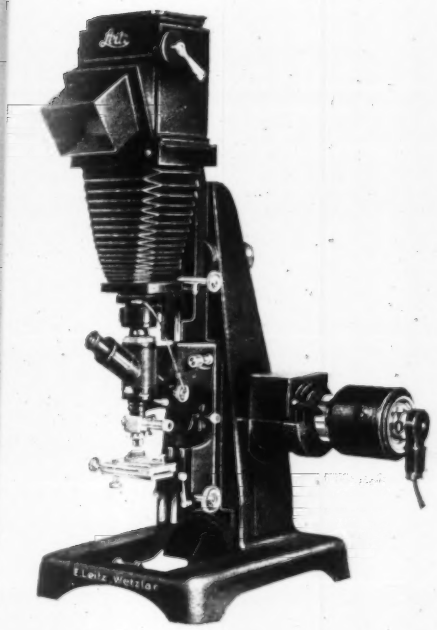
X-Ray Inspector

New visual-inspection X-ray unit for fluoroscopic inspection of food products consists of a motor-driven conveyor supplied in length or width adaptable to an existing production line, and required

X-ray generating apparatus and controls. X-ray tube and high-voltage transformer are immersed in oil in a tank beneath conveyor belt. In the top of a lead-lined tunnel (dimensions of which depend upon material to be inspected) is fluoroscopic screen upon which image is projected. Unit may be installed in a darkened room or a small hood may be provided over viewing screen. Control of X-ray equipment is centered in a small mobile control stand; controls for conveyor system are also in a convenient location on side of machine.—*General Electric X-Ray Corp., 2012 Jackson Blvd., Chicago, Ill.*

LEITZ PANPHOT

The Most Universal Equipment for Microscopic Research



Equally convenient for visual observation and photo-micrography.

Equipped with mirror reflex box to facilitate alignment and focusing for photography.

Usable also for micro-projection, drawing and photo-macrography in transmitted or reflected light.

The equipment includes accessories for:

Examinations in transmitted light (Brightfield);

Darkfield observations from lowest to highest magnifications;

Examinations in reflected light (Vertical Illumination);

ULTROPAK Illumination;

Every type of illumination as cited above can be arranged for in ordinary or polarized light.

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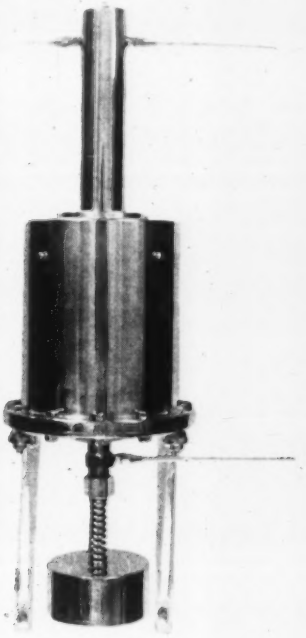
Pressure Booster

Designed especially for testing gages, castings, connections and pressure vessels in the shop or laboratory, this new rapid pressure booster requires no special pumps or motors to build up pressures but operates from the regular



source of water or air supply. It consists of a low-pressure cylinder into which is connected a line from the plant water or air supply system, and a high-pressure cylinder with a lead out to the gages or lines to be tested. The booster is mounted on the test bench, or other convenient places, with the necessary connections and valves to operate it. By manipulating a valve from the plant pressure supply line, pressures can be built up to 5000 lbs./in.^{2} at a slow steady rate or as rapidly as desired. Various capacities and various pressure specifications are available. — *Martin-Decker Corp., Long Beach, Calif.*

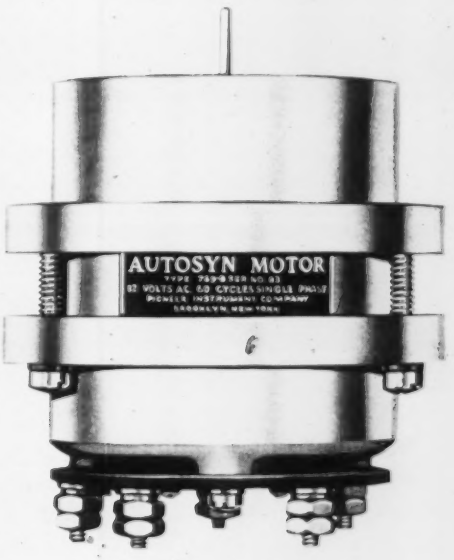
Photoelectric Relay

A new photoelectric relay using Vitron phototubes is designed primarily for use on 110-120 volt, 50-60 cycle current, but is also available in other a-c.

voltages and frequencies. The "No. 5351-D" illustrated uses a 3" lens aperture for increasing sensitivity; other models are available with 2" lenses, with rectangular apertures and no lenses, and with no aperture for use with separate phototube housings. — *G-M Laboratories, Inc., 1731 Belmont Ave., Chicago, Ill.*

"AUTOSYN"

Self-Synchronizing Motor



TYPE 769B
ACTUAL SIZE

Type 769B, the smallest self-synchronizing motor manufactured, is suitable for a wide variety of remote indication applications. Slight movements of sensitive elements such as diaphragms and Bourdon tubes may be instantly and accurately transmitted to duplicate or triplicate indicators.

Size—2⅜" diameter x 2⅜" long
Weight—10 ounces
Current—.16 amperes
Voltage—32V. A.C.—60 cycle
Power consumption—2 Watts
Heat Rise—15°C.
Peak Torque—40 Gram. Cm.
Maximum lag — approximately 1½ Degrees
Shaft Diameter—1/16"
Ball Bearing Equipped

PIONEER INSTRUMENTS

Pioneer Instrument Company, Incorporated

BROOKLYN, NEW YORK

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Radio Laboratory Sets

Four new laboratory sets in quartered oak cabinets with convenient sloping panels and large accessory compartments

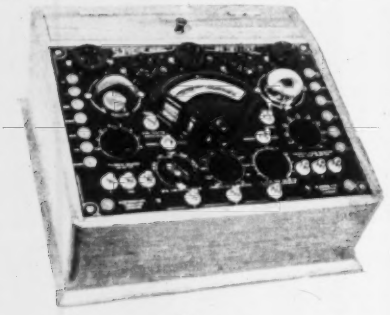


Fig. 1

are announced. The instruments proper are duplicates of their portable counterparts in both electrical design and quality. The "89 DeLuxe Laboratory Model", (Fig. 1), for tube testing and preliminary service work, incorporates an English reading tube scale, neon tube leakage test, English reading capacitor tester, neon capacitor tester, d-c. voltmeter ranges up to 1250 volts, 3-range ohm-

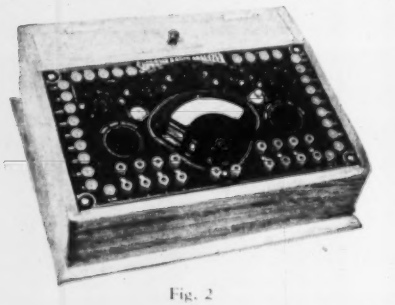


Fig. 2

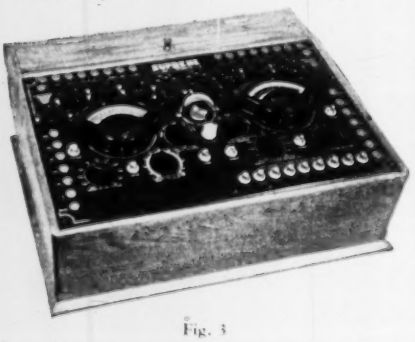


Fig. 3

meter and 2-range megohmmeter which measures to 20 megohms. The "339" is utilized in measuring currents, potentials, resistances, etc., in a defective radio set or amplifier so that proper servicing methods may be pursued. It incorporates all necessary analyzing circuits with direct resistance measurements to 20 megohms and includes the "Supreme free reference point system" of analysis with

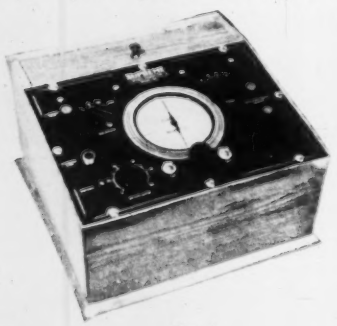
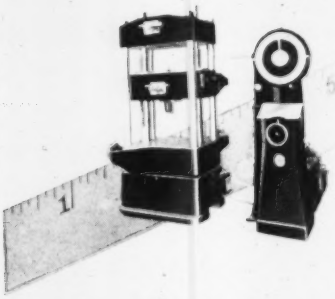


Fig. 4

ONE TEST IS WORTH A THOUSAND EXPERT OPINIONS



ACCURACY

One characteristic traditional to Riehle is accuracy. Take this Precision Hydraulic tester — plunger and cylinder are ground and lapped to mirror-like surface, so accurate that neither is more than .0002" out parallel or round. Only a slight film of oil separates the two— a film that assures frictionless operation and true reading when the load is brought to bear on the plunger. If you don't know the full details about the Riehle Precision Hydraulic Testing Machine, write us. It is built in sizes from 20,000 lbs. to 600,000 lbs., a rugged, sensitive and dependable unit invaluable in your testing work.

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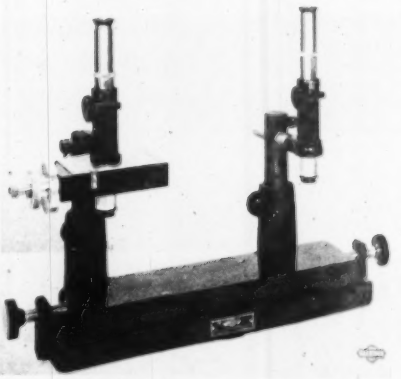
RIEHLE DIVISION

plug and cable. The "385 Automatic Laboratory Model," Fig. 3, combines the features of the "339" and the "89." This is said to be made possible through the Supreme "Uni-Construction" method. The "189 Laboratory Model" signal generator, Fig. 4, facilitates correct alignment of succeeding r-f. and i-f. stages in receivers by serving as a miniature radio transmitter with variable output and frequency controls. It incorporates an electron-coupled circuit with four controls and three tubes. *Supreme Instrument Corp., Greenwood, Miss.*

Comparator for Mortar Specimens

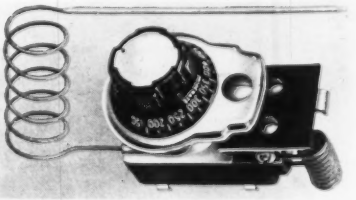
Designed for the accurate linear measurement of cement and concrete specimens in research and routine testing, this new apparatus consists of two microscopes mounted on adjustable supports on a rugged base. Integrally cast



with this base are two microscope supports and a flat and a V guide to transport the stage. One microscope is firmly clamped into its rod support while the other is mounted in a precision micrometer slide of 25-mm. range reading direct to 0.01 mm. Instrument can be supplied with English instead of Metric graduations. Stage has a flat machined surface to receive specimens. Two abutting screws shift the stage in order to place one index on specimen under stationary microscope. Micrometer slide is then used to place other microscope over other index, and its position is then read off on micrometer head. Micrometer slide and microscopes are detachable and can be used separately for numerous other measurements. — *Gaertner Scientific Corp., 1211 Wrightwood Ave., Chicago, Ill.*

Hydraulic Thermostat

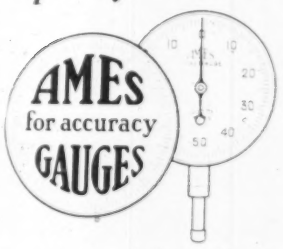
Designed for use in domestic or industrial electric ovens, dryers, incubators, sterilizers, water heaters, glue pots, etc.



Small bulb "cannot be damaged if struck," and "calibrations" are made without removing knob. A low-voltage pilot light with red indicating bull's eye is optional.—*The Hart Mfg. Co., Hartford, Conn.*

AMES GAUGES

Openly Visible



A good view of the working parts is often advantageous with any mechanical contrivance, more so when it can be had without a tear-down.

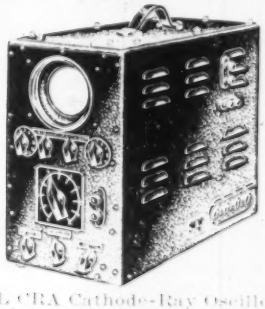
With the backs removed from Ames Gauges, the most vital parts are exposed to view. The operation of the movement can be examined minutely from many angles before any parts are disassembled. Such full exposition promotes the need of quality in finish and appearance. The polished and heavily plated parts radiate the excellence of the interior as well as the exterior of Ames Gauges.

B. C. AMES CO.

WALTHAM, MASS.

CATHODE-RAY

Oscillograph Equipment



MODEL CRA Cathode-Ray Oscillograph is complete with two built-in high sensitivity amplifiers, linear sweep circuit, and grid control synchronization for image lock-in.

Employed for examination of voltage and current wave shapes, transient phenomena, phase relationship, magnetic field characteristics.

Price complete with all tubes, 3-inch Cathode-Ray tubes in portable carrying case—$84.50.

CLOUGH-BRENGLE INSTRUMENTS

MODEL 79 Audio Frequency Voltage Generator

MODEL 66 Radio Frequency Voltage Generator

MODEL UC Thermionic Tube Voltmeter

MODEL 85 Portable All-Purpose Combination Voltmeter, Ammeter, and Ohmmeter

Write for complete literature

The CLOUGH-BRENGLE CO.

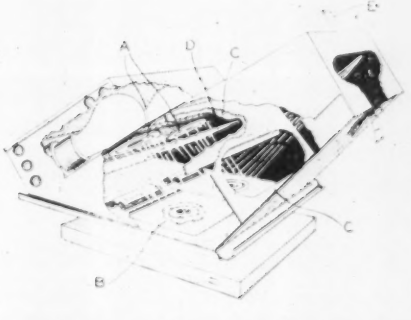
1130-M West Austin Ave., Chicago, U.S.A.

Flow Signaling Device

Swinging-vane type of force fluid metering device, designed for alarm purposes as in connection with sprinklers, and hence provided with electric contacts but not with an indicator and scale. Consists of (a) housing with its contact equipment, (b) flexible paddle suspended from the electrical unit and (c) strap to hold the housing in assembly over a hole cut in the pipe line. The paddle, of flexible material, can be inserted in a hole considerably smaller than its extended diameter. An alarm can be sounded on a sprinkler line in the event of fire or accidental sprinkler operation. Pumps, valves, motors, ventilators can be made to operate on starting, stopping or fluctuating flow. An electrical retard can be specified to prevent operation resulting from momentary surges, hammer or sudden pressure change. Electrical units are mounted on the housing under a molded glass cover. Those parts subject to corrosion are suitably protected. *The Autocall Co., Shelby, Ohio.*

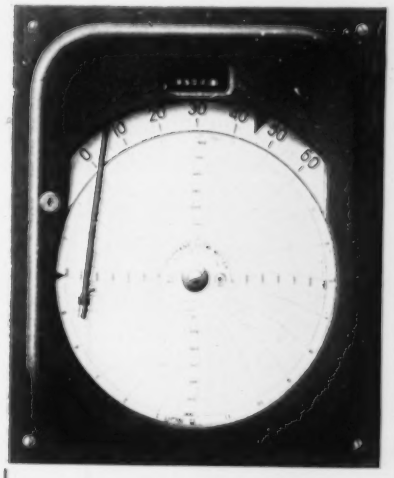
Hunter Gloss Comparator

Particularly applicable to the study of the gloss of high-gloss surfaces which reflect images. Equipped to measure the "distinctness-of-image" type of gloss on



a scale graded from 0 to 100. With the camera which is furnished, the instrument can be used to photograph and give permanent records of gloss and surface texture. Two identical targets, A, composed of rings of different widths, are illuminated from behind. One is reflected off test surface B; the other target is diffused by means of ground glass plate D. Motion of this plate varies diffusion, and its position is noted on the gloss scale E. *Henry A. Gardner Laboratory, 2201 New York Ave., N.W., Washington, D. C.*

COCHRANE FLOW METERS



Cochrane Electric Flow Meters use the galvanometer null principle, universally acknowledged as the most accurate means for measuring a force or quantity. These meters are ideal for central panel installations.

Write for complete information

COCHRANE CORPORATION

Dept. INS

Allegheny Ave. and 17th St., Philadelphia, Pa.

Do you know your vacuum?

Let the TRU-VAC gauge tell you—accurately—continuously. Records pressures from 0—10,000 microns. Invaluable in processes requiring dependable knowledge of vacuum conditions.

Its numerous advantages are outlined in our bulletin TV2, gladly sent upon request.

CONTINENTAL ELECTRIC CO.

St. Charles 6, Illinois

PHOTOCELLS VACUUM SWITCHES

"Truflex" is a busy man in instrument control—holds important jobs. In recording instruments for stratosphere flights, deep sea studies, and other scientific research, Truflex compensates for, or indicates, local temperature conditions. And in other instruments it provides intermittent current control, excessive-temperature protection, and many other necessary features for instrument control.

Truflex is a permanently fused laminated bimetal that reacts instantly to temperature changes. It is consistently uniform, accurate and dependable. It has added extra precision and positive temperature control to hundreds of products at low cost. Find out what it can do for yours.

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Coil and Condenser Tester

Utilizes new method of "electrically selected cam angles." A motor-driven cam actuates three sets of breaker points: first set of points is set at 20°

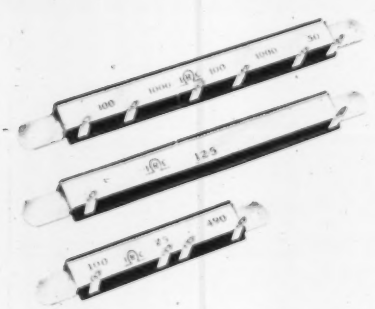
cam angle representing high-speed operation; second at 30°—representing medium speed; third at 40° representing low speed. Spark gap calibrated at 20 mm. is used in conjunction with motor and breaker points. Coils under test are pre-heated electrically under time control. Condensers are tested by a circuit employing a neon glow tube. *Stromberg Motoscope Corp., 2150 Lawrence Ave., Chicago, Ill.*

Safety Transformer

This new type of transformer, developed for increasing the safety factor in inspection or maintenance service, is particularly designed for use where inspections or maintenance must be done with electric illumination and in moist or damp places in buildings permeated with explosive vapor or fumes. Likewise, its use around any machinery, boilers, tanks, etc. reduces shock or explosive hazards. A primary cord, rubber-covered and Underwriters' listed, may be plugged into any 110-volt 60-cycle circuit. The two secondaries to which extension cables are attached each consist of vulcanized approved cable with special non-pull-out-plugs. An ordinary pull on the extension will not break the circuit. *Acme Electric & Mfg. Co., Cleveland, Ohio.*

Calibrated Resistors

"MW" insulation is rated at 1,000 volts, RMS 60-cycle (1400-v. peak) applied between the resistance element and the metal plate on which the resistor is mounted. Resistors are rated at the power dissipation which produces a tempera-



ture rise of 100° C. above a surrounding temperature of 40° C. when mounted against a metal surface, and under such heat conditions (140°) tests reveal that "MW" will operate without changing any of its normal physical or electrical properties. — *International Resistor Co., 401 N. Broad St., Philadelphia, Pa.*

Photo Electric Apparatus

These instruments incorporate the Lange supersensitive cells and are therefore suitable for high-accuracy as well as low intensities.

Among the instruments are—
UNIVERSAL COLORIMETER for use with liquids, powders or solids.

ILLUMINATION METERS of various types—direct reading or recording.

PHOTOELECTRIC CELLS of highest sensitivity for photometric or colorimetric work.

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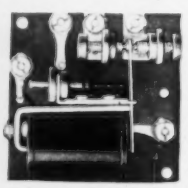
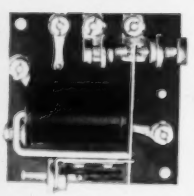


2 New D. C. Sensitive Relays

2C



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INSTRUMENTS and METHODS for Measuring Driving Skill

By HARRY R. DeSILVA

Bureau for Street Traffic Research, Harvard University
Administrator WPA Project on Investigation of Driving Skill
Formerly Director Psychological Laboratory, Massachusetts State College

OUTSIDE of a few "pedestrian's fault" accidents, the principal causes of America's high motor casualty rate are (1) bad driving, (2) bad cars, (3) obsolete roads. The use of instruments can cut down the amount of bad driving and the number of bad cars. The problem of bad driving is one of (a) unfit drivers and (b) uneducated drivers. The tests described by Professor DeSilva make it possible to yank off the wheel those who lack the requisite aptitudes, and to educate those who only need to improve their skill. — MFB

INTRODUCTION

DRIVING a motor vehicle requires concentrated effort in addition to certain potentialities such as good sensory equipment, motor coördination, emotional control,[7] and judgment.[34] When roads were slow and cars so constructed that few could exceed 20 m.p.h., nearly anyone was fit to drive. Today, as is proved by our alarming and increasing accident rate (almost 1,300,000 accidents[1, 24, 29] last year), many autoists do not possess the greater ability required.

In our laboratory we test both the potential and the acquired skill of drivers by means of special instruments which duplicate certain emergency situations on the road, and which give more accurate and more significant indications of the driver's responses than could possibly be obtained by unaided human observations.[16]

The investigation was initiated in September, 1934, under the Massachusetts Emergency Relief Administration, and continues under the new Works Progress Administration.

The first and most important purpose of this investigation was to analyze driving ability. To do this we devised and constructed a considerable number of pieces of apparatus to measure accurately under standardized conditions the basic factors which go to make up driving ability; such as reaction time, eye-hand-foot coördinations, and speed-and-timing estimation.

Fig. 1. Braking-reaction test apparatus

The evolution of our program — the selection of the tests and the design of the different pieces of testing equipment — has been governed by practical considerations:

1. Because of inadequate funds, certain parts of our equipment, which would have been better if purchased, had to be laboriously constructed by hand.

2. We have endeavored to design our tests so that they might consume as little time as possible, in order that we might test several hundred people a day at auto shows and similar gatherings. Our aim has been to devise a battery of tests which can be taken in approximately twenty minutes.

3. We have endeavored to make our tests interesting and to retain some of the atmosphere of actual driving conditions. It is true that glare sensitivity may be tested without having the observer face two automobile headlights, but it is difficult to convince the ordinary man that this is so.

4. Since we usually go to our subjects, instead of having them come to us, we have tried to keep down the size of our equipment so that it can be transported by truck.

Using our experience and that of others[5, 15, 12, 28, 31, 32, 33] who have contributed to this field of work, we have devised a series of tests, which now include the following:

1. Braking-reaction Test
2. Steering Tests:
(a) Miniature Steering
(b) Combined Steering and Braking
(c) Full-sized Steering
3. Speed-and-timing-estimation Test
4. Visual Tests:
(a) Glare-blindness
(b) Movement Perception
(c) Depth Perception
(d) "Tunnel Vision"
(e) Visual Acuity
(f) Color-blindness
5. Auditory Test
6. General Tests including the Training of Drivers:
(a) Miniature-highway Driving Test
(b) Moving-picture Driving Test
(c) Experimental Road Car
7. Tests for Fatigue and other Physiological Handicaps

1. BRAKING REACTION

Emergencies such as result in collisions cannot usually be anticipated. When a collision looms ahead of us, we want to "stop quickly"[15] but it takes an appreciable time for us to react; *i.e.*, to appreciate danger and start to apply the brake. Our braking reaction timing equipment, Fig. 1, duplicates the arrangement of the controls in a Ford V-8. A regulation red and green traffic signal is located in front of the subject, who is told to put his right foot upon the accelerator when he is ready, and to leave his left foot in any convenient position. Pressing upon the accelerator starts the cam of a motor selector switch, which turns on a green light. Thereafter, at an interval which varies with each trial, the selector switch turns on the red light. When the red light comes on, the subject removes his

Fig. 2. Miniature steering test apparatus

foot from the accelerator and depresses the brake pedal as quickly as possible. This short accelerator-to-brake reaction time is measured by an accurate synchronous-motor, clutch-type timer* calibrated in hundredths of a second.

Should the subject anticipate the red light, a buzzer "razzes" him for cheating; he quickly accustoms himself to refrain from "jumping the gun." After two practice trials, five successive reaction times are recorded. The subject's braking-reaction time is the average of these.

We found in testing more than 1,000 people that the average reaction time is around 0.44 second. The shortest on record is 0.24 second. Longer reaction times, up to 1.00 second, have been recorded.

Youths of about 23 have the fastest braking reaction time. From this age on, the time lengthens gradually. There is not much connection between braking-reaction time and driving experience. Quickness seems to be an inborn potential factor, not much improved by actual driving experience. Many other investigations have done work on reaction time, most of them using Dr. F. Moss' pistol method of obtaining results.[2, 6, 19, 20]

We have recently perfected another timing device† for use in an automobile to measure braking reactions under actual driving conditions. It appears that braking-reaction time is longer under road conditions than under the simpler laboratory conditions, but we have not yet performed a sufficiently large number of tests to report conclusive findings.

2. STEERING SKILL

(a) *Miniature Steering Test.* Fig. 2 shows one model of the apparatus designed to measure skill in steering. Seated in a regulation automobile seat, the subject looks at a miniature road scene. In a 20-second practice period he discovers that his dummy car has a greater than normal tendency to wander off the road, but that by manipulating his steering wheel he can keep on the road. This means that he must observe carefully any slight change in the direction of his car, so as to compensate for it by turning his steering wheel; if his car goes to the right, he must turn his steering wheel to the left, and so bring the car back upon the road. A cam, cut to give an irregular series of back-and-forth movements during a period of a minute, controls the motion of the car. Steering ability is measured in terms of the percentage of time that the driver is able to stay in his lane during the one minute period of the test.

The data obtained from more than 3,000 people disclosed a definite correlation between steering skill and driving experience. Experienced drivers make the better scores, and these correspond to the length of time they have been driving. The tests showed also that as a group women learn to steer less readily than men but continue to improve longer. Men improve in steering ability up to about ten years of experience, and then start to decline. After 25 years' experience, men and women seem to approach equality in steering ability. Children under 15 do poorly; children over 15 show marked improvement; young people from 17 to 21 make the highest scores of all. After 55 there is an increasing loss of driving coördination.

(b) *Combination Braking and Steering Test.* An improvement upon the Miniature Steering Test has been the introduction of a small-sized traffic signal into the "roadscape"; a red light is flashed at odd intervals during the test, and the braking-reaction time of the subject measured while he is under the necessity of keeping his car upon the road. We have found that braking-reaction times are often 0.2 second longer when measured with the accompanying distraction of the Steering Test than when measured on the Braking Test alone. The Steering Test scores are correspondingly lower when the distracting traffic lights are operating. Inexperienced drivers find this test particularly difficult since they have not yet learned how to carry out several activities simultaneously.

(c) *Full-Sized Steering Test.* Fig. 3 shows our Full-Sized Steering Test apparatus—the outcome of our attempts to make our Miniature Steering Test more realistic. The subject sits in a full-sized Ford V-8 cab and observes the moving highway in front of him through a

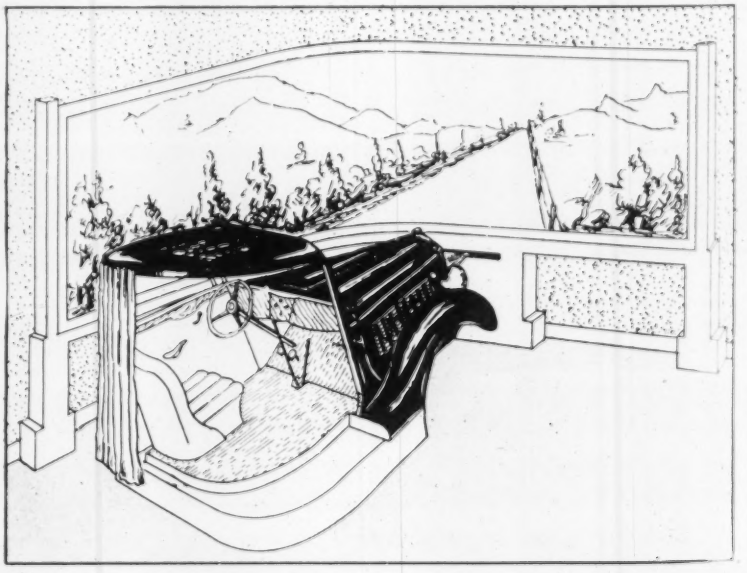

Fig. 3. Full-size steering test apparatus—General view

*Supplied by the Standard Electric Time Co., Springfield, Mass.

†Fig. 17, described in the latter part of this article.

frosted windshield on which a clean sector has been cleared by a windshield wiper. A cam drives the moving highway scenery in such a way as to give him the illusion of driving along a road. He soon finds that it is not easy to keep his car in the proper lane, for the car wanders back and forth and he must keep turning his steering wheel to stay on the right side. The score for this test is obtained in the same way as in the Miniature Steering Test—by measuring the percentage of time that the subject is able to keep in his lane. Dr. A. R. Lauer and the National Institute of Industrial Psychology have also devised equipment for testing steering ability.[17, 29]

Fig. 4 shows part of the mechanism which produces the illusion of driving along a real highway. The essential elements are three revolving cylinders upon which are painted highway scenes in colors. The two vertical cylinders contain powerful lamps which project upon the rear of the screen a picture of moving roadside scenery. Similarly, the horizontal cylinder produces the illusion of a moving road.

Since our Steering Tests correlate well with driving experience, we feel that one of them should form a part of the examination for a driver's license.

3. SPEED-AND-TIMING ESTIMATION

Many of us have had the experience of riding with a person who makes blunders in passing cars on the open road when a car is coming from the opposite direction. The probable reason is faulty speed-and-timing estimation, an especially dangerous defect, since few who suffer from it are aware of their inaptitude. 61% of the deaths in the past three years occurred on perfectly straight stretches or between intersections. 75% occurred on dry roads and 84% on clear days.[1] The modern death trap is apt to be a straight, busy highway on a clear, sunny day. The sudden vision of a broad, straight road tempts many a driver into passing the car ahead. If his ability to estimate speed is defective, he may make a gross miscalculation in passing and collide head-on with an oncoming car. Similar speed-estimation tests have been devised by Forbes[11] and Miles.[19]

Another symptom of faulty speed-and-timing estimation is lack of confidence. Safe driving involves a proper balance between going ahead at a reasonable speed when

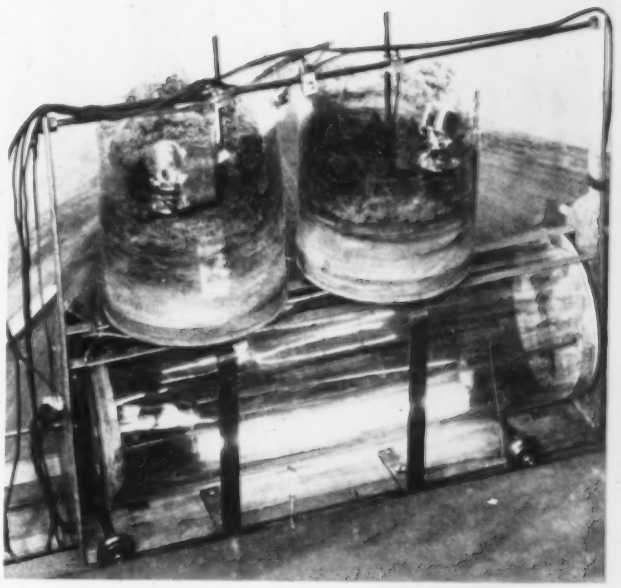

Fig. 4. Full-size steering test apparatus—Projectors

conditions warrant, and holding back when they do not. The confident motorist drives so as to interfere as little as possible with the other cars on the road. The uncertain driver, on the other hand, holds up a line of cars on the highway, and thus encourages other drivers to take risks in order to pass him. With a device such as our speed-and-timing apparatus, the hazards arising from irresolute, erratic driving could be greatly reduced by *training* drivers to estimate relative speeds of cars correctly and to make up their minds quickly when to pass.

In our speed-and-timing apparatus, Fig. 5, we have two cars proceeding down a road at different speeds, the rear car moving more rapidly than the leading car. The cars come into view for about one-third of the course; and then, as they disappear from view, the subject is asked to judge the point on the scale at which the pursuing car will catch up with the other.

In giving this test to several hundred people, we observed great differences in ability to estimate speed correctly.[25] Most people erred in their estimation in a negative direction; that is, they estimated that the rear car caught up with the front one before it actually did.

In addition to having the subject estimate the particular point at which the fast car catches up with the slow one, we asked him to judge *when* the event occurred. There are some people who do better on speed estimation than on timing estimation, and *vice versa*.

It has been called to our attention many times that speed estimation of automobiles traveling at right angles to the observer, as in this test, may be different from estimating the speed of oncoming automobiles. To investigate this method we set up a piece of apparatus with which subjects could judge the speed of oncoming cars. With this apparatus we found that ability to estimate the speed of oncoming cars correlates with the specific ability determined by the test shown in Fig. 5.

Fig. 5. Speed-and-timing test apparatus

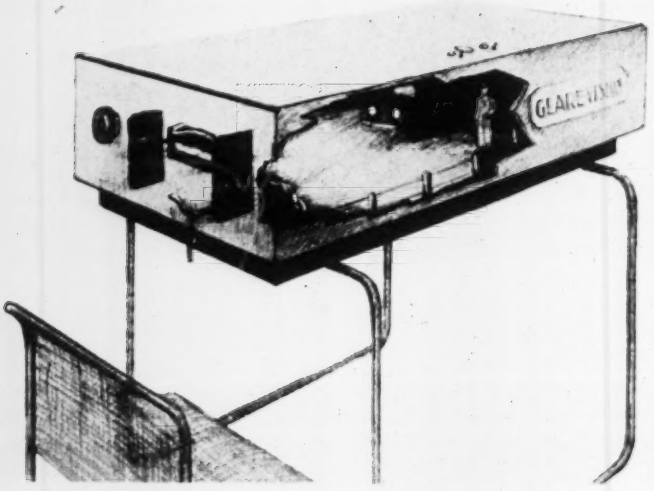

Fig. 6. Glare vision test apparatus

1. VISUAL TESTS

Of all the senses involved in driving an automobile, vision is of paramount importance.[14] The color-vision and acuity tests are of less significance than tests which measure (a) Glare-blindness, (b) Depth Perception, and (c) "Tunnel Vision."

(a) *Glare-blindness.* Some people are blinded much more by headlights than others;[4, 5] in fact, their disability is serious enough to be designated as glare-blindness.[15, 17, 18] For testing this headlight glare-blindness, we have devised the novel apparatus illustrated in Fig. 6. The person taking the test looks into a closed box where he experiences the illusion of meeting another automobile with glaring headlights. A miniature pedestrian is located on the right-hand side of the highway. The subject has his own set of headlights with which he can control the total illumination on the road, and he is told that he must increase the intensity of these headlights until he is able to see the pedestrian. He is scored according to the amount of increased brightness (of his own lights) necessary for him just to perceive the form of the pedestrian.

In trying out our glare test on several hundred people, we found that some of them were glare-blind to such a degree that we had to reduce the glare of the opposing headlights; and even then, with their own headlights turned on full, they experienced difficulty in detecting the pedestrian's presence. It is obvious that many drivers are glare-blind and don't know it!

If this apparatus should be made available throughout the country, it would in time do much to teach glare-sensitive people to be more careful about their night driving. It could also be used with advantage in educational work among bus or truck drivers who *have* to drive at night.[16, 18]

Recent investigation has shown that *night-blindness* is connected with a deficiency of Vitamin A.[32] Possibly it can be corrected or lessened by the addition of a plentiful supply of this needed vitamin to the diet of people so affected. Since glare-blindness is associated with night-blindness, we should like in our further work to experiment with the vitamin A content of the diet of glare-sensitive subjects to see if we can improve their glare vision.

(b) *Depth Perception.* Another factor contributing to safe driving—especially in passing—is an accurate sense of depth perception. To test it we use the depth-perception apparatus devised by Capt. Howard and employed in the U. S. Army Aviation examination.

The device, Fig. 8, consists of two vertical rods, one of which is permanently fixed on a base, while the other, under control of the subject, can be moved toward or away from him. They are located side by side and seen against a white background at a distance of 20 ft. from the subject. His ability to judge comparative distances is estimated by the results of a series of attempts to put the movable rod exactly alongside the fixed one.

After two practice trials, five judgments are made. An individual who persistently places the movable rod more than 25 mm. away from the fixed rod experiences great difficulty in learning to fly. The automobile driver who is similarly defective is probably a hazard to himself and others on the highway.

(c) "*Tunnel Vision.*" The normal driver or pedestrian can look straight ahead and still be able to detect a vehicle coming toward him on either side. Some persons, however, can see only in front of them—as if they were looking through a tunnel. They cannot see a car approaching from a side road or coming around from the rear, until it is almost in front of them. Restriction of vision to less than 60° on each side is decidedly dangerous.[10, 12] Fig. 9 shows a perimeter with which we measure "tunnel vision." While the subject looks straight ahead of his own image in the mirror, the examiner moves the light box out from the center along the curved iron rod until it passes out of the subject's sight. This procedure is carried out for both left and right side. The angles at which the light disappears from the subject's view express the scope of his peripheral vision; they tell "how far he can see out of the corner of his eyes."

Fig. 7

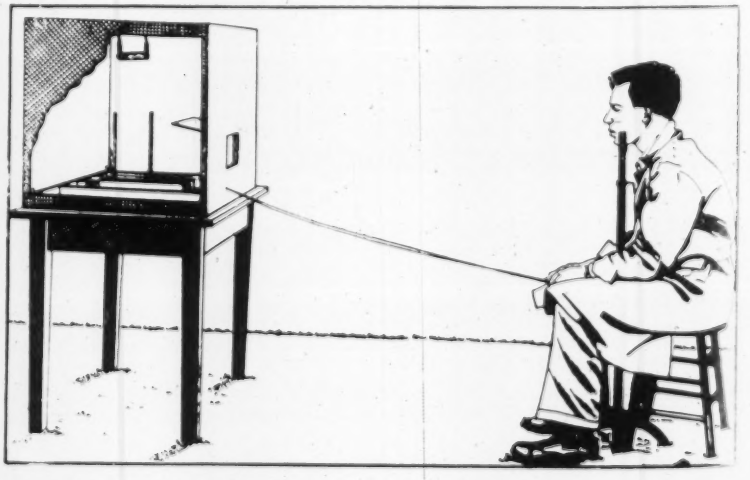

Fig. 8. "Rod test" for depth perception and judgment of distance

(d) *Visual Acuity.* The relative importance of visual acuity, or keenness of vision, in automobile driving has as yet not been accurately determined, but it is evident that a person with poor acuity has a handicap of which he should be aware so that he may compensate for it. A simple device for measuring visual acuity is the Landolt Ring Test, Fig. 7. The subject, seated a definite distance from the screen, is asked to judge the openings in each ring while the operator brings into view successively smaller incomplete rings until the subject is unable to discern the position of the opening. Since acuity is partly dependent upon illumination of the test object, a fixed intensity of artificial illumination is maintained. Another simple apparatus for testing acuity is a Keystone Stereoscope*, Fig. 10, supplied with specially designed cards for separate monocular and binocular tests.

Fig. 9. Perimeter for "tunnel vision" test

(e) *Color-Blindness.* Since many people are unaware that they are color-blind, or color-weak, a disability of this kind may be a serious source of confusion, if not of accidents. We have found by testing several thousand people that there are many who, though color-blind according to the Ishihara Test, are able to distinguish between the red "Stop" and green "Go" traffic signals. We therefore use the red, yellow, and green lenses of *regulation traffic lights* to measure the subject's color defectiveness. As shown in Fig. 11, the observer is asked to tell what color appears behind the opening in the box when there is no possibility of his anticipating the order of presentation of the colors.

Fig. 10

5. AUDITORY TESTS

When one has a backseat driver as a passenger, inability to hear may be an aid to one's driving. Otherwise, subnormal hearing ability is a decided disadvantage: a warning signal from a passing car or a locomotive whistle may not be heard. To measure auditory efficiency we have designed a portable, simply operated audiometer. With it we measure the intensity threshold of motor-vehicle operators, and test for the presence of any tonal gaps, or deafness to certain pitches. By informing drivers of their hearing disabilities, we enable them to compensate by exercising increased vigilance or by equipping themselves with hearing aids.

6. GENERAL TESTING, INCLUDING THE TRAINING OF DRIVERS

Most of the tests described thus far have been tests for specific aptitudes that are essential for driving. It is desirable to supplement these tests with others which determine *composite* of skills required under actual-driving conditions. To avoid the chief disadvantage of the usual road driving examination and at the same time retain many of its advantages, we have devised the following equipment: (a) a miniature highway driving test; (b) a moving picture driving test; (c) an experimental road car. Beside being used for testing, the devices described below are also planned to teach beginners to drive and increase the efficiency of retarded drivers.[23, 24]

(a) *Miniature Highway Driving Test.* Since it is impossible to have the observer move down the road in the limited space of a laboratory, we move the road (an endless belt) toward the observer. The driver sits in a standard automobile seat with regulation steering wheel, brake and clutch pedals, starter, accelerator, ignition switch, gear lever, and emergency brake, all in their usual positions. As he turns on the ignition and puts his foot on the starter, he hears the motor start. After he has manipulated the clutch in the customary manner and gone into gear, the road starts moving toward him at a speed which represents his road speed. Cars on his side of the road traveling faster than he does move ahead of him, while those traveling toward him on the left come nearer. He finds, as he speeds up, that he can pass the cars going in his direction, although in doing so he

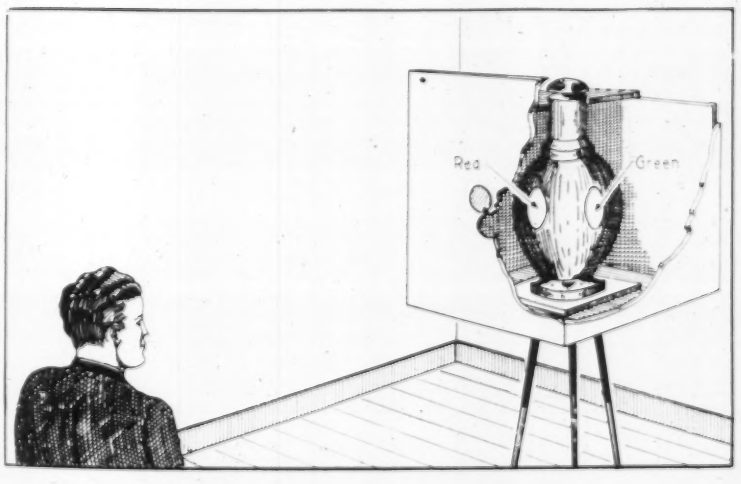

Fig. 11. Standard traffic-light test for color-blindness

* Supplied by the Keystone Co., Meadville, Penna.

must exercise caution to prevent a collision with oncoming cars. The apparatus for this Miniature-Highway Driving Test is shown in Figs. 12, 13 and 14. To determine how the driver will act in emergencies, he is placed in as many dangerous situations in three minutes as would be encountered in many years under ordinary road conditions. On at least one occasion during the period of the test, an accident occurs: when it does, the driver's miniature hood and windshield swing back violently with a loud crash. Graphic records are made of the driver's performance during the period of the test. This miniature-highway test is a sort of omnibus test that can be used for measuring a number of different factors. Excellence of performance on it can be measured in terms of:

1. The number of cars passed safely;
2. The number of accidents;
3. The number of *cut-ins*;
4. The number of excursions to the ditch;
5. The behavior of the driver in the accident situation;
6. The correct use of the brake;
7. The driver's manipulative ability in starting up the car and putting it into gear;
8. The driver's vigilance shown in anticipating and avoiding dangerous situations;
9. The driver's emotional control.

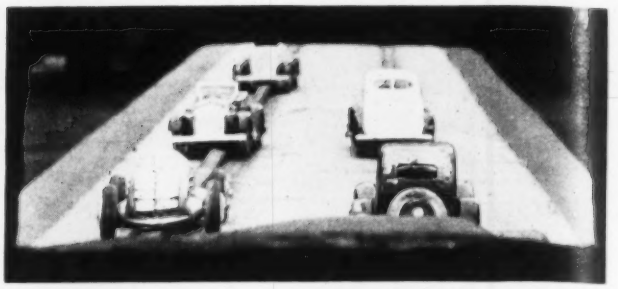

Fig. 12. The miniature highway as it appears to the driver looking through windshield.

Fig. 13. General view of miniature-highway driving test apparatus.

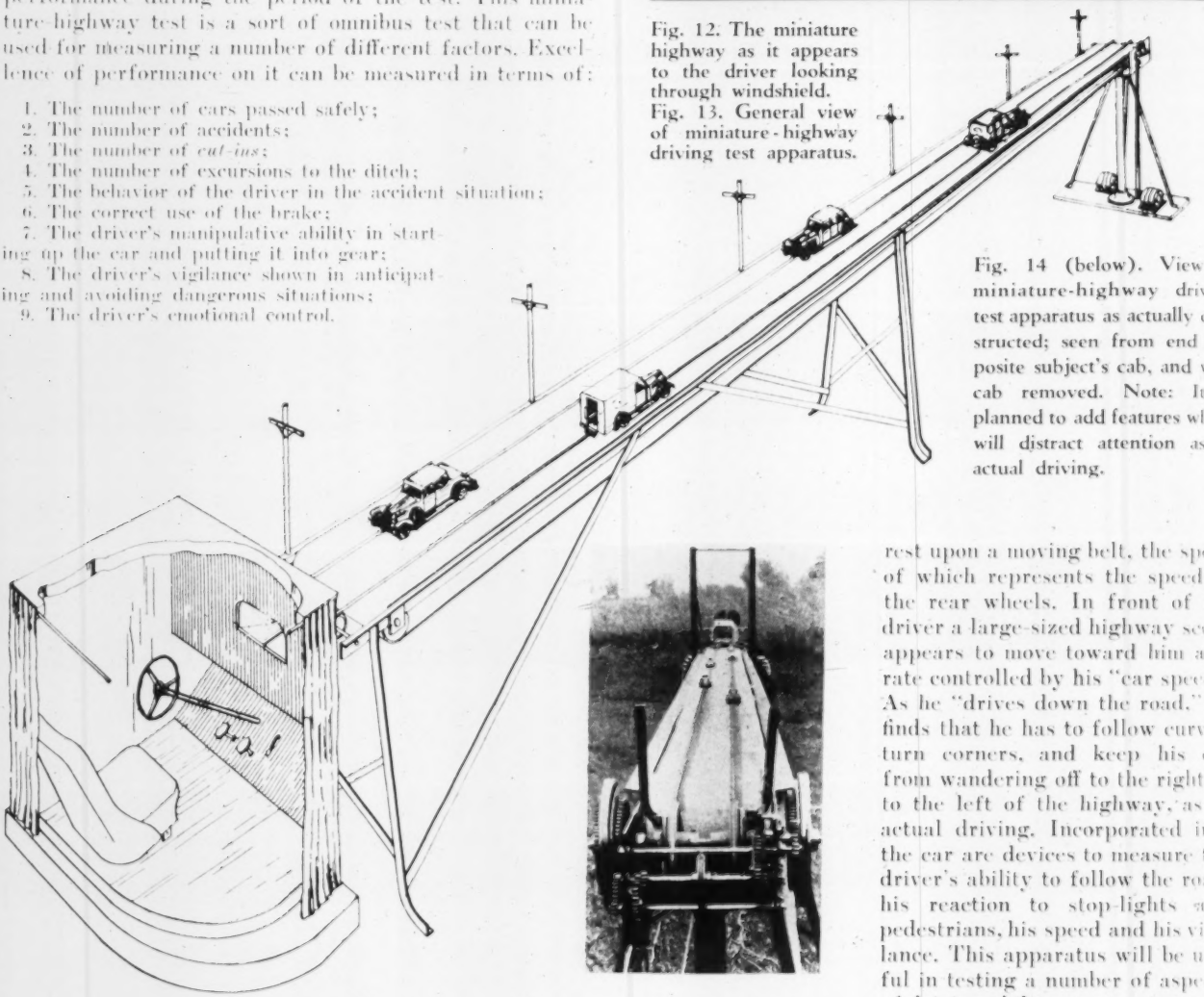

Fig. 14 (below). View of miniature-highway driving test apparatus as actually constructed; seen from end opposite subject's cab, and with cab removed. Note: It is planned to add features which will distract attention as in actual driving.

At this writing we have not completed a sufficient number of tests to make definite reports. These will be made through official channels; in this article we only describe equipment of interest to the readers of *Instruments*. We are thankful to Dr. Theodore W. Forbes for lending us part of his Miniature Highway Test and for permission to make use of his original scheme.[11]

The Illuminating Engineering Society has requested us to elaborate upon this test so as to make a scientific study of the human factor in night driving under different conditions of highway illumination. We propose to replace the 60-watt Mazda lamps by miniature highway illuminants.

Plans also include the addition of telegraph poles, trees, etc., to the roadside, and the installation of traffic lights and side roads as additional sources of distraction.

(b) *Moving Picture Driving Test.* Fig. 15 shows the design of an apparatus under construction. When the subject starts the car, the rear wheels revolve on rollers, while a cable keeps the car in place. The front wheels rest upon a moving belt, the speed of which represents the speed of the rear wheels. In front of the driver a large-sized highway scene appears to move toward him at a rate controlled by his "car speed." As he "drives down the road," he finds that he has to follow curves, turn corners, and keep his car from wandering off to the right or to the left of the highway, as in actual driving. Incorporated into the car are devices to measure the driver's ability to follow the road, his reaction to stop-lights and pedestrians, his speed and his vigilance. This apparatus will be useful in testing a number of aspects of driving ability at once, in teaching prospective drivers, and in interesting the public in better driving.

(c) *Experimental Road Car.* The final step in realism in our laboratory testing program is to take the laboratory out on the road. In Figs. 16 and 17 are shown some of the devices which we have incorporated into an experimental testing car used on the highway. Beside a set of dual controls, which facilitate the process of training individuals to drive skillfully, we have included devices to measure hitherto neglected reactions of the driver, internal as well as external, which may be responsible for accident-proneness.

7. Detection of Fatigue and Other Physiological Reactions

A common cause of accidents is fatigue or drowsiness. But since the driver has himself to blame when he falls asleep at the wheel, he often wittingly or unwittingly conceals his condition, in case he lives, in explaining the cause of the accident. Thus the significance of drowsiness

in the production of accidents is probably much underrated. We have built several recording devices in the experimental car to measure driving fatigue.

Of great importance to safe driving over long periods of time is the facility with which one handles the steering wheel. We measure two aspects of this ability: the change in steering-wheel grip, and the change in manipulative activity in directing the car. To measure the former we have designed a *steering-wheel-pressure recorder* (A in Fig. 16). It records electrically the pressure exerted by the hands gripping the steering wheel. (In this connection it may be noted that some drivers tire themselves out unduly by gripping the wheel with too great force. The device can be used to educate such persons.) We measure the latter with a *rotary-steering-movement recorder* (D in Fig. 17), which makes a continuous record of the turning movements of the steering wheel while the car is being driven. The fresh driver anticipates the drifting movements of the car and manipulates his steering wheel smoothly to keep his car going ahead evenly on a straight line. A drowsy operator, on the other hand, does not respond so rhythmically and smoothly to the wanderings of the car on the road.

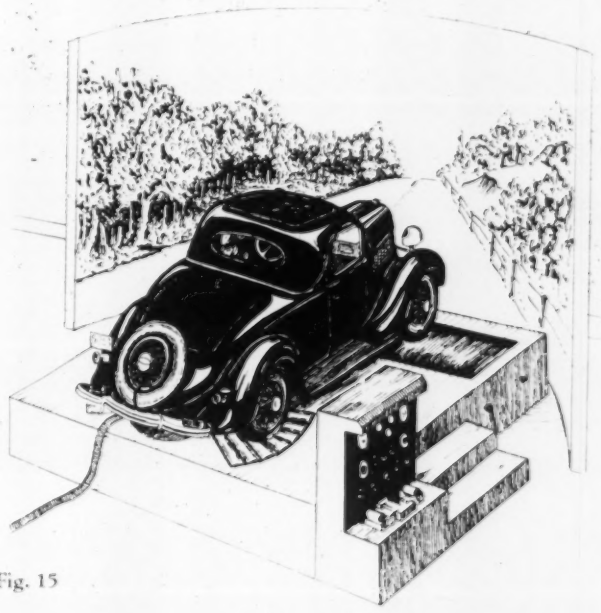

Fig. 15

A car that demands more strength to steer also fatigues its driver more quickly. A *friction brake* attached to the steering wheel of our experimental car and adjusted to make it more difficult to steer (to approximate the conditions in steering a large truck) permits us to measure how much and in what ways the driving problem is complicated by additional resistance in steering mechanism.

Drivers shift around from time to time so as to relieve strains caused by sitting in the same position for a long time. To measure and compare these movements in fatigued and rested drivers, we have *a body movement recorder* to show the movements of the subject in his seat.

An *electrical timer* to measure brake reactions in hundredths of a second (C in Fig. 17), records the braking reaction times of fatigued individuals. A *dynamometer* records the pressure on the brake exerted by the fatigued driver.

For testing excitability, a so-called *psychogalvanometer* measures electrical skin resistance. We include it in our fatigue tests because experiments have shown that certain changes in skin resistance indicate emotional disturbances and also reveal a general mental "let down." It is possible to measure the skin resistance of a driver in an automobile with comparatively little inconvenience to him by placing two small electrodes on relatively immobile parts of his body.

We propose to use our experimental car to discover some of the specific ways in which varying degrees of alcoholic intoxication affect driving ability. The dual controls obviate the possibility of any accident. Walter

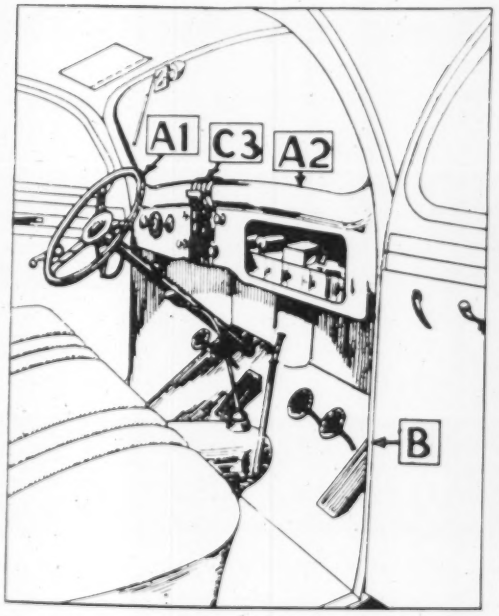

Fig. 16. Front-seat details of experimental car. A1—Steering-wheel grip; A2—Recorder; B—Examiner's controls; C3—Braking-reaction timer.

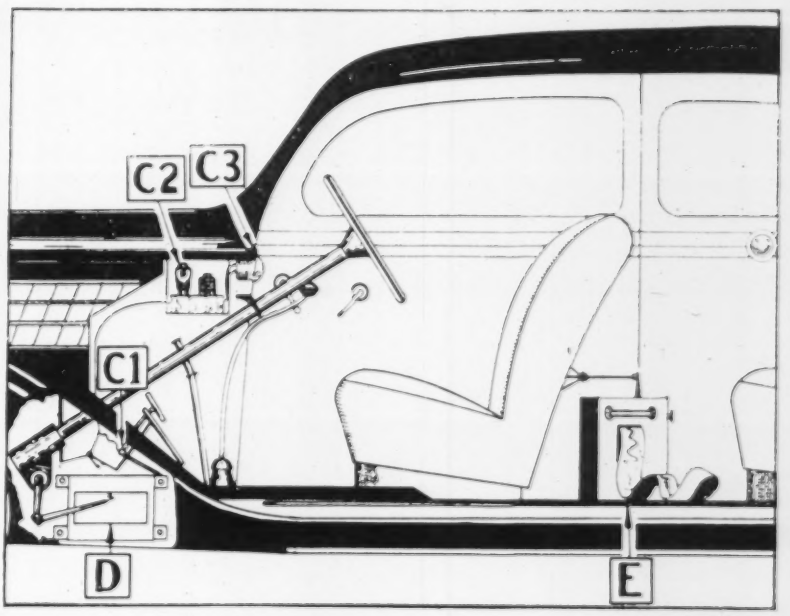

Fig. 17. Experimental car. C1—Braking-reaction time contacts; C2—Relays; C3—Timer; D—Rotary-steering-movement recorder; E—Driver's seat-movement recorder.

R. Miles is the author of one of the best articles on alcohol in relation to motor vehicle drivers.[21]

CONCLUSIONS

The majority of motorists have good intentions but they need adequate training.[22, 23] To examine drivers and point out their driving faults so that they can correct or compensate for them would be far more effective than continually to admonish them for their mistakes with the threat of forbidding them the use of the highways.[27, 35] Our object is not to supply difficult tests to restrict more persons from driving but to make better drivers.

There are a number of people whom no amount of training would make safe drivers: senile persons, people with serious sensory or motor defects, people who have a fear of driving and "go to pieces" easily in emergencies, fall into such a category. These persons must be legislated off the highways, but they are in the minority and we are here concerned with the more serious problem of the majority. Ultimately there must be undertaken a systematic testing and training program for the individual driver. Equipment such as ours could be used by motor vehicle registries all over the country and explained publicly at lectures, auto shows, expositions, and science museums. Such a program would cost money, but the outlay would be small compared with the social and economic benefits.

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INSTRUMENTS' BOOK SHELF

The Measurement of Inductance, Capacitance and Frequency. By ALBERT CAMPBELL and ERNEST C. CHILDS. Macmillan and Co., Ltd., London. Cloth, 6x9 inches, 488 pages. Price 30 shillings.

A comprehensive review of this book cannot be undertaken in a few paragraphs, and the authors have not provided a foreword which readily adapts itself to the reviewer's purpose, except to state that the earlier part of the book is based on a series of articles written for Glazebrook's *Dictionary of Physics* and brought up to date by the addition of much new matter.

The work opens with an excellent discussion of elementary a-c. circuits and sources of alternating current, following through from the simplest alternators to a great variety of elaborate oscillating systems and networks. Two chapters are devoted to measuring and detecting instruments, showing the advantages and limitations of each type. No less than 42 pages are devoted to vibration galvanometers alone.

The whole subject of inductance is treated, from the most elementary calculations to the actual construction of self and mutual inductors, leading up to transformers, which are considered as a special form of mutual inductance, thus permitting a unique and precise consideration of the aspects of ratio, phase-angle and losses, without the necessity for involved mathematical processes. The first ten chapters may be considered as preliminary to the subject of measurement of inductance, which subject is introduced by simple methods utilizing ordinary deflecting instruments. The actual testing of transformers is handled rather briefly as compared with the general subject of mutual inductances.

An important and interesting chapter on the significance of the inductances of measuring instruments provides a distinct contribution to the art of instrument design.

Capacitance is treated in a manner similar to inductance, one chapter being devoted to theoretical considerations of the physics of capacitance, one to dielectric constant, power loss, phase-angle, etc., of the three basic classes of dielectrics—plates, films, and fluids—including a comprehensive table of dielectric constants of materials, and one chapter to the principles and construction of condensers—solid, air, gas, oil, and electrolytic, wet and dry, fixed and adjustable. Capacitance measurement according to four essential principles is elucidated in a chapter of 43 pages.

The measurement of frequency is approached in the sense of an essential to the determination of capacitance and inductance, six basic methods being classified. There are described a number of frequency meters hardly known in American practice. Ten deflecting types are treated, as well as a vast number of frequency-sensitive networks, many utilizing the principles of resonance. There appears a detailed discussion of piezo-electric principles showing various applications of quartz resonators as precise frequency standards.

The book closes with four chapters devoted to a-c. potentiometers, their construction and uses, thus in a complete and satisfying manner rounding out the general subject of determination of fundamentally alternating-current magnitudes.

Illustrations are profusely used—453 of them—for the most part original and explicit diagrams and graphs, together with 43 tabulations of data. While mathematical treatment of some of the more intricate problems is essential, and, when used, is meticulously exact, the definite and successful effort which has been made to eliminate superfluous use of higher mathematics will [illegible] to popularize the book among practical engineers.

The bibliographical work is remarkably complete, the writings of some 420 authors (predominantly European) being quoted in approximately a thousand references, identified, and distributed as footings on pages to whose text they are relevant. More than sixty of these are references to prior works of one of the authors of this book. In addition to the usual subject index, there is an index to these citations under the names of the respective authors who have been quoted. There is also an Appendix giving a list of some fifteen modern standard works of reference. The conventional Table of Contents occupies sixteen pages and lists by title and number each of the 515 paragraphs which comprise the 23 chapters of the volume.

The book shows every evidence of having been undertaken as a sacred duty to science, and there is everywhere apparent the most painstaking care that no stone shall remain unturned in the interests of thoroughness, precision and clarity. The unstinted effort that the work of other investigators shall receive due recognition is most praiseworthy. There is little doubt that this work of Messrs Campbell and Childs is destined to take its place along with Ewing's "Electromagnetic Induction" and Thompson's "Dynamo-Electric Machinery" among the imperishable classics of electrotechnical literature.

PERRY A. BORDEN (4)-B-

Fig. 1. Student engineers are trained in the dismantling, assembling and repairing of instruments and control systems.

Training Instrument Men Where Instruments are Made

By R. C. KENNAN

Manager, Service Dep't, The Brown Instrument Co., Philadelphia, Pa.

A Division of Minneapolis-Honeywell Regulator Co.

WITHIN recent years the advantages of intelligent instrument application have become more evident to industrial leaders. The possibilities of improved production with the aid of automatic control devices have led to much industrial research and development work in which the trained instrument man has been of greatest assistance. On the whole, industry is rapidly becoming instrument minded, and the educational development of its instrument personnel is an important factor. Such special education is now available to concerns that desire to take advantage of it.

In a recent *Instruments* article* a well-informed Industrial Engineer emphasized the importance of employing a technically trained instrument man to supervise the care and application of instruments. Such a man, properly trained in the servicing of industrial pyrometers, flow meters, thermometers, electric and air controls, etc., and educated to understand and visualize manufacturing problems, is of immense value to any industry. The importance of this position justifies the selection of a man of the highest type at a salary commensurate with his responsibilities.

It is well recognized that we cannot all be expert accountants, engineers, artists, etc., and so it is with instrument work. A competent electrician or mechanic may turn out to be a poor instrument man. The man selected for this purpose should preferably have a technical foundation in mechanical, electrical or chemical engineering or physics, with a strong leaning for practical application and an ability to work with his hands. Men who have ridden hobbies or had interests along electro mechanical lines seem to be particularly adaptable to the instrument field.

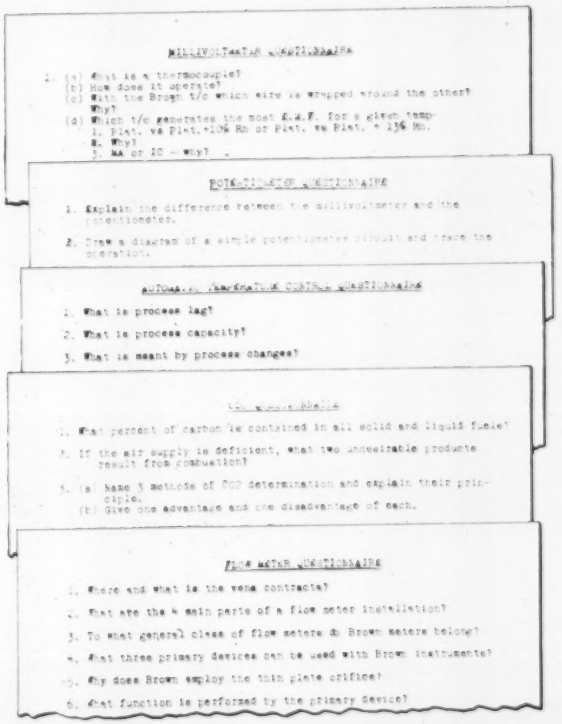


Fig. 2. Typical "final exam." questionnaires.

After selecting a suitable man, industrial concerns have been confronted with the problem of how and where to train him in the art and science of servicing instruments. Leading instrument manufacturers, recognizing the importance of properly educating men in the adjustment and application of their equipment, have established educational and training facilities not

*"Selecting and Training Plant Instrument Men. G. P. Bosomworth. *Instruments*, Nov. 1935, pages 285-288.

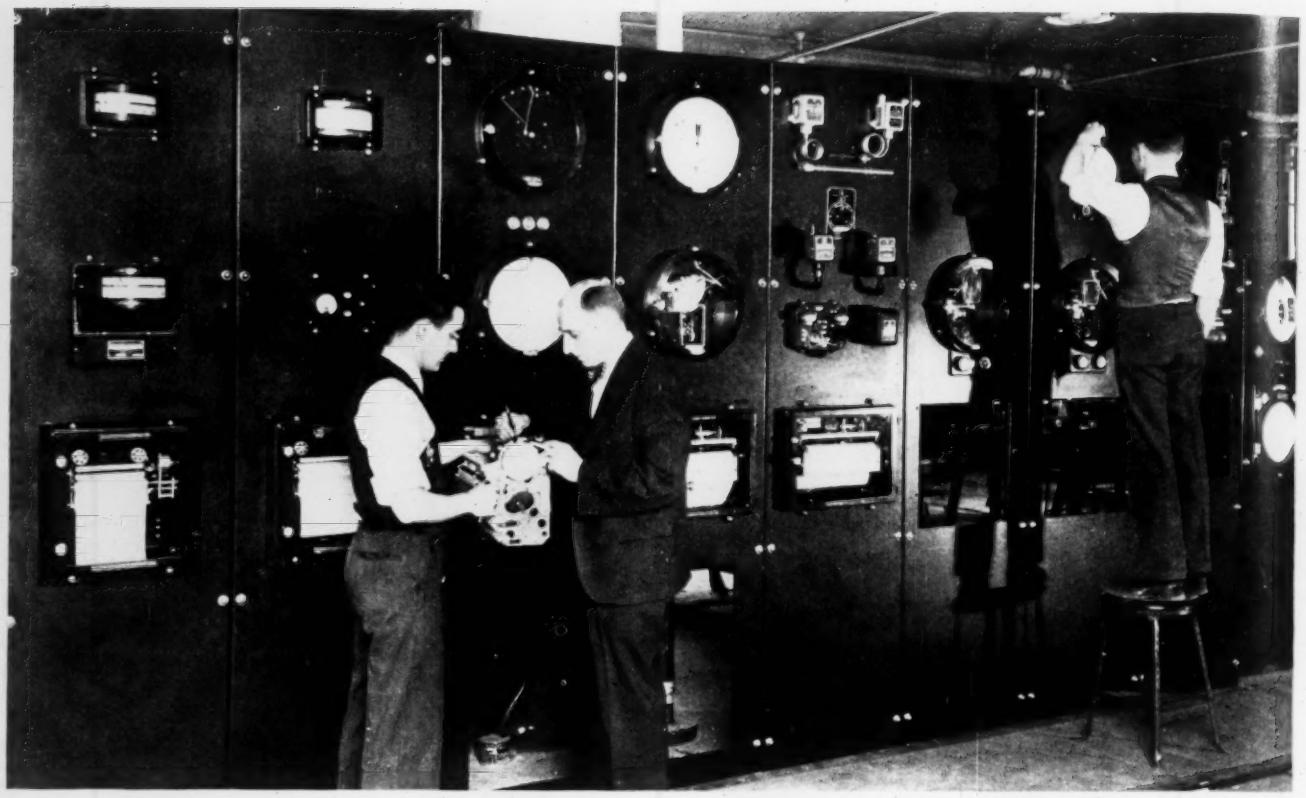


Fig. 3. Students at work on a panel board equipment. They are taught to erect panels and install instruments and to wire up meters in the most approved manner. After the student rebuilds and adjusts his instrument or meter, he mounts it up on the panel and proceeds it put it into operation, under the guidance of the instructor.

only for their own personnel but for users of their equipment. The scope of training at any one manufacturer's school is generally limited to his own line of equipment. However, the basic principles of operation and application are sufficiently uniform for the student engineer to grasp them from any authoritative source. While this article applies specifically to the Brown Instrument Co., it is the intention to illustrate the facilities that are available in this country to train men for industrial instrument work.

It is almost as important to provide for the student engineer's welfare and contentment during the training period as it is to provide for his instruction. The time allotted to the work is generally from two to ten weeks, depending upon the number of types of instruments to be covered and the kind of instruction desired (supervisory, maintenance, etc.) so that the student engineer has little time for study during his working hours. He must do most of his study and paper work at night. He should therefore be provided with good, clean, comfortable living quarters, preferably close to the plant. Such facilities are generally available at nominal expense, upon advance request through the plant to be visited. The Brown Instrument Co. has so established its procedure that the student does not have to spend a lot of time getting acquainted with his surroundings. There is no floundering about from one department to another seeking an education in piece meal fashion. He is turned over to the Instruction Supervisor, Mr. R. A. Weikel, whose thirteen years in instrument development and research work, and whose intimate knowledge of the line, enable him to place the student engineer in the proper channels. Complete instruction facilities are brought to the student in one department. Mr. Weikel devotes his full time to the Training School and to the preparation of Training Bulletins, Questionnaires, etc.

In view of the limited time available for training purposes, it is important for the prospective student or for his employers to formulate in advance some well-defined idea of the types of instruments which he is to study; and to decide whether his instruction is to be for actual instrument servicing or for general supervisory purposes. The average capable man, with a background as suggested previously, has been found to master the details of repairing and servicing an average of one type of instrument or meter per week. Some types of meters and control systems require the attainment of skill in the handling of tools and parts in addition to acquiring a knowledge of the general construction of the meter. This type of meter generally requires about two weeks' study by a man who is to do repair and servicing.

Supervisors are generally interested only in a working knowledge of the instruments and can thus cover the subjects in shorter courses.

The following outline will indicate the scheme of the general course. Concerns interested only in specific types of instruments can select the sub-course desired, thus economizing on their man's time:

Millivoltmeter Pyrometers, Indicators	1 week
Millivoltmeter Pyrometers, Recorders	1 week
Potentiometer Pyrometers, Single-record	1 week
Potentiometer Pyrometers, Multiple-record	1 week
Flow Meters, Electrical } Flow Meters, Mechanical } Incl. flow calculations	2 weeks
CO_2 Meters, Electrical	2 days
Tachometers, Electrical	2 days
Thermometers, Resistance type	2 days
Pressure Gages: Bellows, Helix, Bourdon tube	2 days
Thermometers, Pressure type	1 day
Automatic Controls, Electrical	1 week
Automatic Controls, Air-operated	1 week

In addition to the practical bench work in which each student is individually instructed, each course ends with a written examination. Fig. 2 gives an idea of the qu

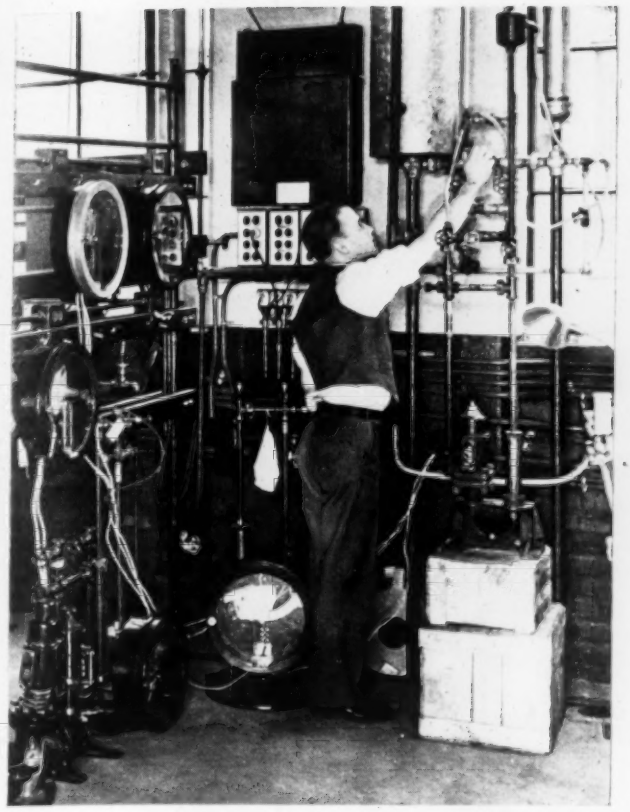


Fig. 4. Practical work in the flow meter course: Student engineer running a water-column test where the conditions are similar to those he would encounter in the field.

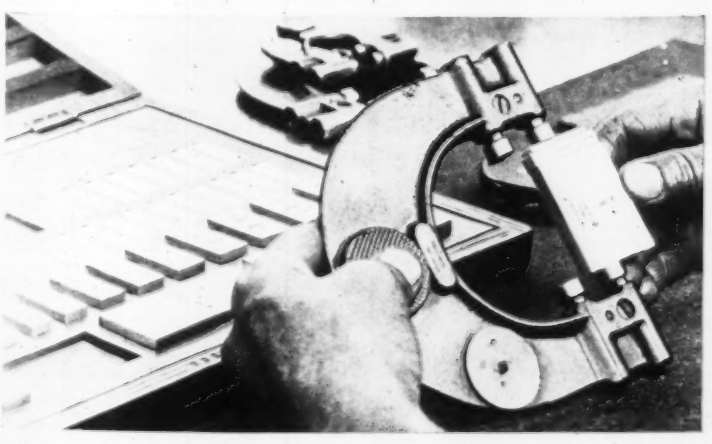
Fig. 5. Student engineers building up a gas-fired furnace for experimental and demonstration temperature control work. Included in the practical work of the course is the proper adjustment of air-gas ratio valve settings, running piping, wiring, etc. These subjects are purposely included, for the aim of the course is to give a well rounded understanding of the various phases of instrument construction, installation and maintenance.

tionnaires. There is little time during training hours for the study of books, but Béhar's "Fundamentals of Instrumentation" is the reference text, and copies of *Instruments* are passed around.

It is, of course, readily evident that any instrument instruction course can only form the basic ground-work for application and future development. It is not possible to crowd much actual practice and application into a few short weeks, in addition to the study of details of construction. A good instrument man will therefore learn much in his own industrial field after he completes his instrument training course.

Some industrial concerns are located in small communities where there is a limited group of men from which to select their instrument men. Also, some concerns prefer to employ instrument men on the recommendation of the manufacturer. Anticipating this need, The Brown Instrument Co. selects a number of men of the right qualifications, in excess of their own requirements, in each training group. These "extra" men are available for industrial plants where their services are desired at the conclusion of their training course.

There is ample evidence that Instrumentation will be a substantial factor in future production activities in most of the leading industries. Progressive concerns that built up a trained instrument personnel who understand their manufacturing problems will undoubtedly be in a commanding position. Time is an important factor in the education and development of good instrument men; and concerns which have not already done so will find it advisable to start training their personnel as early as possible and while training facilities are readily available.



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Auxiliary Equipment for Cathode-ray Tubes

Tenth part of "The Cathode-ray Oscillograph and Its Applications" being published serially in *Instruments*. This series began in the July 1935 issue.

By RALPH R. BATCHER

Radio engineer; cathode-ray and electronic application specialist, Hollis, L. I., N. Y.

LINEAR TIME BASE

Addendum

The principle of charging a capacitor through a resistor and discharging it through a gas-filled tube is employed in the linear sweep of the new Clough Brengle oscillograph, Fig. 25a. This equipment is based on the operational features of the RCA Type 906 cathode-ray tube. Its circuit[1] is shown in Fig. 25b. A single transformer supplies potentials to two interlocked rectifier circuits which supply operating voltages to the oscillograph tube, the linear sweep circuit, and two amplifier tubes. Provision is also made for the use of a 60-cycle (sinusoidal) time base. All of the usual operating connections, when the oscillograph is used in normal tests, are internally controlled by three special switches, *V*, *H*, and *S*. The *V* switch has two positions and connects the applied waves to the vertical deflection plates either directly or through an amplifier. The latter uses a single type 57 tube and is controlled by an input voltage divider, *G*. The horizontal deflection is controlled by the switch *H*, which is set on one of its three positions, to the 60-cycle sweep, the linear sweep, or to some external circuit. Deflection amplitudes are in the latter two conditions controlled by the voltage divider *H*. The third switch, *S*, controls the application of the interlock potentials for the linear sweep, which consists of a capacitor *C'*, charged at the desired rate through the resistance *R*, and periodically discharged through the gas tube 885. The voltage variations across the condenser are amplified by a 2A5 tube to permit ample deflection swings with but small voltage variations across the condenser. The controls *A* and *B* are arranged to center the diagram on any portion of the screen.

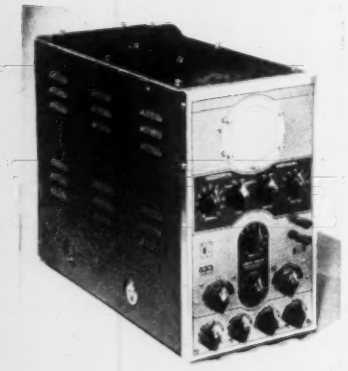

Fig. 25a

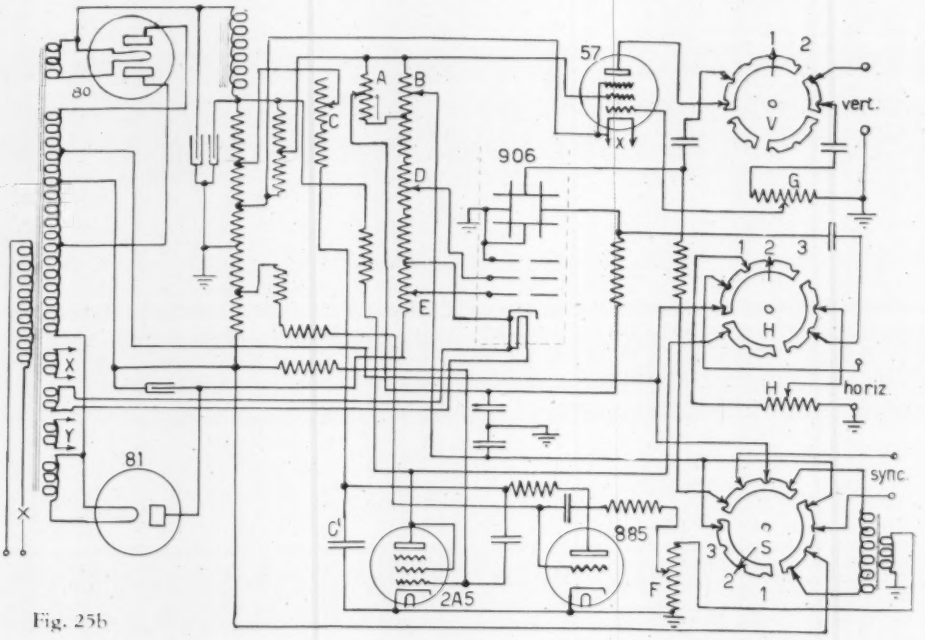

Fig. 25b

THE CIRCULAR TIME BASE[31, 32, 33]

In the study of recurrent phenomena or cyclic disturbances of any nature, it generally is possible to utilize a circular time base to good advantage. With this method the time base has a greater length for any particular screen diameter and permits the delineation in a manner readily analyzable, of several curves which are superposed for direct comparison. A handicap of the cathode-ray oscillograph (that of a limited screen area) is overcome with this arrangement. A circular time scale was used as early as 1915 by Lilienfeld[34] and many forms have been used since. Fundamentally, the principle is to produce a circular trace by rotating the spot at a definite rate, as by applying a known frequency to a rotator circuit (hereinafter described) and then to apply to the system the wave under study so that either vertical or radial excursions are produced in addition to the circular motion, thus producing a "gear wheel" appearance. This section will be devoted to (a) methods of rotating the spot and (b) methods of producing the supplementary deflections.

If 60-cycle potential is applied to any of the circuits described below, the spot will rotate 60 times per second. Theoretically there is no limit to the frequency that can be applied to these circuits, as long as the cathode-ray tube can be focused accurately at the higher deflec-

[31] Chubb, Polar and Circular Oscillograms, *Electric Journal*, Vol. [illegible] 1914, pages 262-267.

[32] Anon, Polar Coordinate Studies with Cathode-ray Tubes, *Archiv für Technisches Messen*, Sept. 1933, J-834-14.

[33] U.S. patents:
No. 1768262, Phase measuring circuit, Marrison.
No. 1882849, Frequency production, Marrison.
No. 1882850, Frequency production, Marrison.

[34] German patent DRP 373834, 1915.

tion velocities. In radio transmitter modulation tests (to be described) and in the measurement of phase differences, radio frequencies up to several megacycles are used. In other applications related to the study of certain industrial processes, the spot may move slower than one revolution per second, the eye does not see a complete circle unless a "slow" screen is used—of a material with marked phosphorescence. At frequencies higher than about 24, persistence of vision makes the observer see a circle and the eye cannot detect the motion of the spot.

For most practical applications it is desirable that the speed of rotation bear some definite relation to the frequency of the phenomena investigated. This is usually not difficult in the case of electrical investigations since many effects occur at the frequency of the a-c. line. In other cases electrical oscillators are readily assembled should a particular frequency be required. In certain tests it is necessary that the rotation occur at a known rate for timing purposes—such as 1000 revolutions per second.

ROTATOR CIRCUITS[35, 36, 37]

The basic principle of these circuits is to apply to each set of deflection plates or coils, potentials of the same frequency but out of phase, usually in quadrature. A phase-splitting circuit is thus necessary to produce an out-of-phase component from a single phase supply.

One simple circuit, shown in Fig. 38, consists of a resistance and a capacitance. Here (if a true circle is required) the impedance of the resistive branch must be equal to that of the reactive branch:

$$R = X_c \quad \text{and} \quad R_r = X_r$$

at the applied frequency. The first condition is obtained by adjusting R or C, and the last condition is usually practically realized since both R_r and X_r are both generally negligible. It also is necessary that the applied potentials have a good waveform.

A number of interesting variations of this circuit are possible wherein the phase-splitting is done by an actual resistance and a capacitance as in Fig. 38A; a resistance and an inductance, as in Fig. 38B; an actual capacitance (C) in one branch, and a virtual resistance (consisting of a low-resistance tuned circuit L C_1 comprising an inductance and capacitance in parallel) in the other branch. At resonance the tuned circuit has the properties of a non-reactive resistance. This arrangement is shown in Fig. 38C.

Other variations may be used, such as by replacing the capacitance C in Fig. 38C with either a resistance, or even by another resonance circuit. At frequencies greater or less than resonance this tuned circuit will act either as a capacitance or as an inductance, and thereby produce a phase displacement between the two branches.

A more elaborate circuit is shown in Fig. 38D which is similar to a circuit used in certain types of a-c. potentiometers. A mutual inductance is used in the quadrature branch, through a series control resistance.

PHASE ADJUSTMENT

While the circuits shown in Fig. 38 (and Fig. 40) are useful in the production of a circular time base, analysis will show that the output potentials vary not only as to phase but as to amplitude. Due to the series resistance in the primary circuit, the line regulation is poor so that changing the phasing circuit affects the load and the voltages change in each circuit. It happens however

[35] Dye. The Cathode-ray Tube Method for Comparison of Frequencies. *Proceedings Physical Society of London*, Vol. 37, 1925, pages 158-168.

[36] Kipping. Neon Tube Time Base Circuit. U.S. patent No. 1592274.

[37] Cramp. Cyclograms for Studying Wave-form. *Journal Institute of Electrical Engineers* (London), Vol. 69, 1930, pages 81-82.

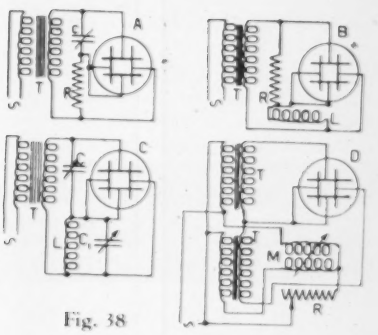

Fig. 38

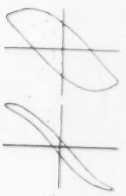

Fig. 39

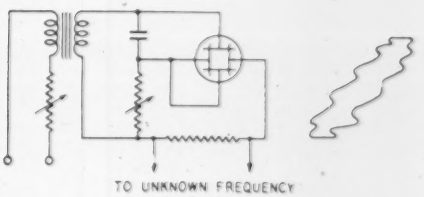

Fig. 40A Fig. 40B

(assuming a sinusoidal output from the secondary of the transformer) that the potentials applied to the pairs of deflection plates are equal whenever phase quadrature is obtained. In any case the actual voltages in each circuit, regardless of phase, can be determined simply by using the cathode-ray tube itself as a peak reading voltmeter. The deflecting potentials to one pair of plates is removed, whereupon the potential on the other pair will produce a straight line on the screen, the length of which can be multiplied by the calibration constant for that particular pair of plates to indicate the volts (peak value). Phase differences can be determined in ways which will be indicated in a separate section devoted to those problems.

The line transformers are added in each of these circuits as a safety precaution, to prevent the grounded anode circuit from mixing up with possible grounds in the power line circuit. At light loads these transformers may have a rather high flux density and the harmonic content of the output wave is large. By loading the secondary winding with a shunt resistance, the harmonic content can be reduced. The exact value of load resistance can be determined by watching the diagram as changes are made. If the harmonics are present (usually odd) a true circle or ellipse cannot be obtained, with any setting. Fig. 39 shows the distortion introduced into figures nominally of an elliptical shape.

APPLICATION OF THE SECOND FREQUENCY

If in addition to the connections to the deflection plates shown in any of the circuits in Fig. 38, a second frequency (assumed for the moment to have a frequency higher than the time base frequency) is applied to one pair of plates, as in Fig. 40A, supplementary swings are introduced around the periphery of the circle or ellipse, producing a diagram similar to that in Fig. 40B. The main disadvantage with this method is that the extra swings are radial in two quadrants only, and are more or less tangential in the other two quadrants and are not distinguishable in these sections.

In order to produce radial movements in all quadrants several methods have been disclosed. Early demonstrations by Wood and others made use of a circuit wherein the unknown wave was applied in series with the anode circuit of the cathode-ray tube, and had an amplitude sufficient to change the deflection sensitivity of the

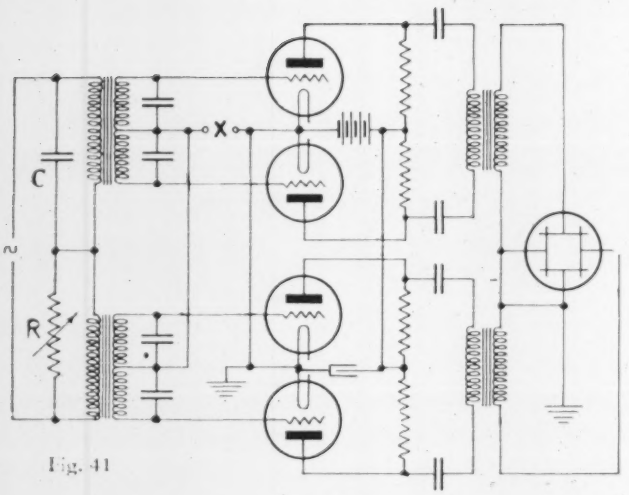

Fig. 41

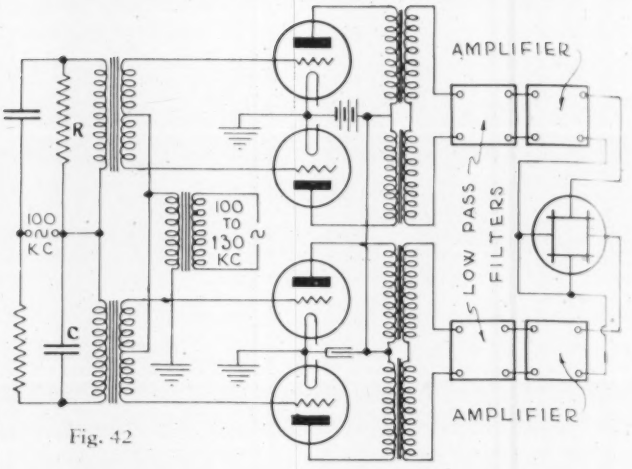

Fig. 42

tube.[37, 38, 39, 40] The frequency ratio between the time base potential and that applied to the anode circuit is exactly equal to the number of teeth on the diagram. With many cathode-ray tubes, however, variations in the anode potential will alter the focus and make the diagram difficult to analyze. Several other circuit variations are possible which will take care of this difficulty and still give the same pattern. In one circuit the quadrature potentials obtained from a standard frequency supply are amplified through two push-pull amplifier stages before being applied to the deflection plates of the tube.[41] The unknown wave (X) is applied to the common circuit of the common grid return of all tubes, as in Fig. 41, and will thus produce true radial deflections. This circuit, shown by Wente and others[42, 43], may seem rather complicated, but by using such tubes as the double triodes now available (type 53, etc.) the equipment is much simplified. If the stages are balanced there is no interaction between the two frequencies. A somewhat different method for obtaining similar results has been disclosed[44] which utilizes a heterodyne type two-phase oscillator from which two audio frequency potentials are obtained with a predetermined (usually 90°) phase difference. Fig. 42 shows the basic circuit used in this equipment. A circular time base of any frequency from 0.5 to 30.0 kilocycles can be obtained. In the original application this equipment was used to check certain features in regenerative amplifier circuits, but it should prove of value in the solution of other research problems as well.

It is possible to apply both frequencies (unknown and standard) to a simple rotator circuit, as in Fig. 43. Ordinarily, however, the higher frequency (usually the unknown) has a negligible drop across the capacitive branch of the circuit and will not produce true radial movements as mentioned above. This effect can be remedied by placing a small inductance *L* in series with the condenser, having an impedance at the higher frequency approximately equal to the value of the resistance *R* in the other branch of the circuit, as in Fig. 43. *R* (or *C*) can be rebalanced to compensate for this change insofar as phase balance at the lower frequency is concerned.

The circuit of Fig. 44 is a variation whereby the higher frequency can be added to each of the primary circuit phases by the addition of a transformer linking arrangement. Transformers should be selected that are efficient at the frequency used.

It is possible to produce radial deflections on a circular time base by connecting the second frequency to a concentric electromagnetic coil, similar to the focus coils described in Nov. 1935. Such a coil may be independent of the rest of the circuit so that the measured frequency need not be "tied in" with the regular circuit. This system requires more power to produce a given radial deflection, and the actual deflection also depends upon the position of the spot on the screen.

This system can be applied in the study of transient surges, ignition coil characteristics, etc. Tests made with a 10,000-turn coil slipped over the tube and connected to a vacuum tube amplifier produced suitable deflection for the study of frequency ratios. It may be noted that the deflections are not truly radial but take place along a spiral path starting at the periphery of the original circle.

CIRCULAR TIME BASE WITH DEFLECTION COILS

In some cases it may be desirable to produce circular time bases with deflection coils, in order to permit the deflection plates to be used for other purposes at the same time. Two pairs of deflection coils (d) mounted at right angles to each other and connected as in Fig. 45 are necessary. Air core deflection coils are recommended for this service. The values of the resistance and condenser impedance are necessarily of the same order as in the other types of circuits, but both should be variable in order to compensate for the impedance introduced by the coils themselves.

[38] Wood. The Cathode-ray Oscillograph. *Journal Institute of Electrical Engineers* (London), Vol. 63, 1925, pages 1046-1056.

[39] Kipping. Demonstration of Cathode-ray Tube. *Proceedings Physical Society of London*, Vol. 37, 1925, pages 265-266.

[40] Moullin. Radio Frequency Measurements. J. B. Lippincott Co., Philadelphia, 1931.

[41] Herd. Generation and Receipt of Short Wireless Pulses. *Proceedings Physical Society of London*, Vol. 45, 1933, pages 221-234.

[42] Wente. A.c. Phase Studies. *Journal American Institute of Electrical Engineers*, Vol. 40, 1921, pages 900-904.

[43] MacGregor-Morris & Wright. Circular Time Base Giving Radial Deflections. *Journal of Institute of Electrical Engineers* (London), Vol. 71, 1932, pages 82-85.

[44] Peterson, Kreer & Ware. Regeneration Theory & Experiment. *Proceedings Institute of Radio Engineers*, Vol. 22, 1934, pages 1191-1210.

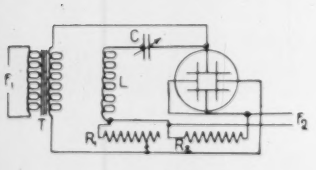

Fig. 43

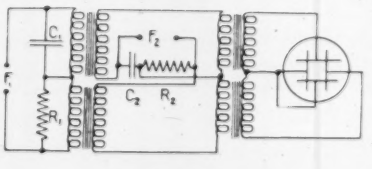

Fig. 44

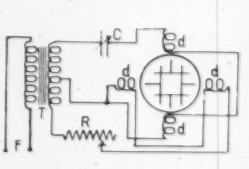

Fig. 45

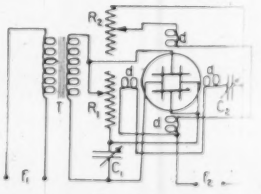

Fig. 46

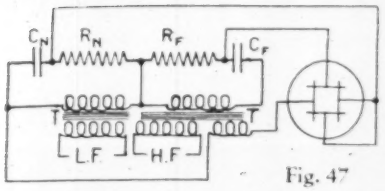

Fig. 47

In still another circuit, Fig. 46, the rotator circuit is applied to the deflection plates to produce a circular time base. Two pairs of deflection coils are connected to the second frequency in quadrature, *i.e.*, one pair through a resistance and the other pair through a condenser. Another circuit has been disclosed by Rangachari[45,46] as reproduced in Fig. 47. Here the two frequencies are each applied to the deflection plates through separate rotator circuits. In this Figure R_N and C_N are adjusted to produce a time base circle rotating at the frequency N, while the values of C_F and R_F are adjusted to control the radial excursions, of the frequency F. In either of the last two arrangements the frequency ratio is not an exact equivalent of the number of teeth showing on the diagram, but corresponds to rules which will be described in detail later.

SPIRAL TIME BASE CIRCUITS

In certain tests, particularly the determination of short time intervals, it may be desirable to use a spiral time base, which will permit a number of revolutions of the spot to take place during the interval taken up by one series of actions. This can be accomplished for example with the Fig. 42 circuit by varying the rheostat in series with the primary at a certain rate, fast enough so that the successive revolutions are not superimposed. With this arrangement time intervals corresponding to ten or more cycles of the time-base frequency can be accurately measured.

The side excursion can be obtained by introducing electrical pulses in series with the anode potential of the cathode-ray tube so as to produce radial or saw-tooth effects, or else by introducing the pulses into the modulating grid circuit of the cathode-ray tube, which will vary the intensity of the trace.

MECHANICALLY DRIVEN ROTATOR CIRCUITS

Such devices are destined to become increasingly important accessories to cathode-ray oscillographic tests. In the majority of industrial applications some cyclic phenomenon is under investigation, the frequency of which is not sixty cycles. The frequency may not even be constant, as in the case of prime movers.

It is possible to produce a circular trace, rotating in synchronism with the master mechanism, by coupling a small two-pole synchronous alternator to the driving shaft of the machine, through one of the phase-shifting circuits shown in Fig. 38. Due to the difficulty of keeping the phase relations between the two branches the same, because of speed variations, the use of a two-phase synchronous alternator of small dimensions has advantages.* Here each phase can be connected to a separate pair of deflection coils, thereby producing on the screen a circular diagram, rotating in exact synchronism with the master mechanism. Potentials controlled by the factors under investigation can then be connected to the regular deflection plates. Several other methods are available, which will be described in detail in conjunction with the applications.

[45]Rangachari, Harmonic Comparison of R.f. Waves with the Cathode-ray Oscillograph, *Experimental Wireless & Wireless Engineer*, Vol. 5, 1928, pages 264-266.

[46]Rangachari, Analysis of Circular Diagrams, *Experimental Wireless & Wireless Engineer*, Vol. 6, 1929, pages 184-193.

*Small Selsyn type motors can often be used for this purpose.

MECHANICAL PRODUCTION OF POLAR CURVES

Certain mechanical problems can be readily solved by the simplification of the diagram that results when the tube is physically rotated or translated in some definite manner. This principle would also be useful in the study of 60-cycle phenomena if the cathode-ray tube were rotated about its own axis synchronously at this speed. The connection to the deflection circuits of potentials that would ordinarily give a circular diagram will then produce a single spot of light. If one set of deflection plates is connected to the 60-cycle line, a circle will appear, located tangent to the axis of deflection, *i.e.*, a true polar curve. If connections are made that would normally produce an elliptical diagram, the appearance will now be a radial line of light, and the direction in which this line points will be a direct indication of the phase relation.

Many interesting effects appear when three-phase phenomena are studied with a rotating tube. Harmonics usually appear as a multiple lobed figure giving a direct indication of the order of the harmonic. The principle involved is not unlike that of an electrical filter where the fundamental is eliminated leaving only the harmonics.

Instead of rotating the whole assembly of electron gun, deflection producers and screen, it is possible to achieve similar results by rotating a set of *deflection coils* around a stationary tube. While this latter arrangement requires a more or less elaborate physical set-up and careful balancing to prevent excessive vibration, it is not impracticable. On the other hand, in a plate-equipped cathode-ray tube which is rotated about its own axis at a speed of more than a few cycles per second, centrifugal acceleration may temporarily or permanently misalign the deflection plates.

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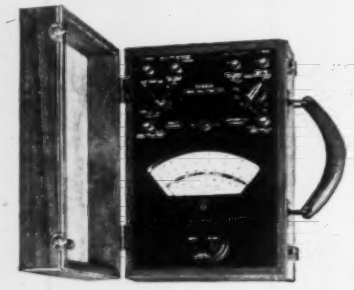

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Sources of Error in Electrical Measurements

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By PERRY A. BORDEN and M. F. BEHAR
Member A.I.E.E. Editor, *Instruments*

In the previous articles of this series only casual reference has been made to the possibility of errors existing in the measurements obtained with electrical instruments, but anyone engaged in the work of industrial measurements is well aware that errors are inseparable from the readings of instruments[1], and though they may be compensated for or corrected out, yet it is important to eliminate the causes as far as possible and make the necessary allowance for the residual discrepancies. It is not the purpose of this article to discuss in full with mathematical analyses all the possible sources of error, but only to treat those which are serious enough to affect the electrical measurements likely to be made with industrial instruments of the types treated in this work.

In some cases, where the design of an instrument has included a deliberate modification with a view to eliminating an otherwise troublesome source of error, this feature has been discussed in previous articles. The references to such features will be made as brief as possible.

Note—The characteristics and uses of watthour meters are so radically different from those of indicating or recording instruments that it has been deemed unwise to attempt in these pages a treatment of the highly specialized subject of their errors and adjustments. These have been dealt with briefly in Sections 3 to 6 and 11 of Chapter XLII. For detailed discussions the reader is referred to the bibliographical appendix and to manufacturers' literature.

In general there may be said to exist three possible sources of error in indicating instruments. These are:

1. Inherent errors of the instrument used
2. Errors due to the method of measurement
3. Errors of observation.

1. Inherent Errors

The degree to which inherent errors may be eliminated from an instrument is governed solely by the expense which it is desirable to incur in the production of the instrument. Since it is impracticable to eliminate such errors entirely, it is usual to reduce their effects by application of a knowledge of their influence. They may be classified as follows:

(a) Temperature errors
(b) Mechanical errors
(c) Electrical defects
(d) Spring errors
(e) Unbalancing

(a) Temperature errors.

Because of space limitations in the actual measuring element of an electrical instrument and the importance of keeping the power consumption in this part at a minimum, the designer of the electrical circuits of these parts is limited to a relatively few metals. Copper, because of its high conductivity as compared with cost, is the most common. Where it is necessary to have the maximum amount of power in an element, without regard to cost, silver may sometimes be employed because of its higher conductivity than copper. In cases where it is desired to have moving conductors of minimum weight, aluminum is sometimes employed. Whichever of these three metals is used, the material is characterized by a relatively high temperature coefficient of resistivity; and the art of the metallurgist has not produced a conductor in which are combined the desirable features of low resistance and low temperature coefficient of resistivity. In instruments such as voltmeters and wattmeters having a potential circuit, in which the flow of a measured current bears to the line voltage a relation governed by the resistance of the circuit, it is important to take into consideration any change in this resistance which may take place upon changes of temperature, whether the temperature variation be due to external conditions or to heat developed in the circuits of the instrument itself. The general effect of heating is to increase the resistance of the electrical circuits, thereby decreasing the current flowing for a given voltage

[1] H. B. Brooks, The Accuracy of Commercial Electrical Measurements, *Transactions A.I.E.E.*, Vol. 39, Part I, 1920, pages 496-536.
Instruments, March 1935, pages 66-69.

thus correspondingly decreasing the actuating forces. If the circuit of a voltmeter or wattmeter were wholly of copper and this all at a uniform temperature, it will be seen that with the temperature coefficient of copper at a value of 0.24 percent per degree F., the current-per-volt would vary nearly 1% for each 4 degrees temperature change, making a most unsatisfactory instrument. As has been pointed out in earlier articles, the great part of the resistance of such a circuit is confined to a series resistor of material having a negligible temperature coefficient, so that the effect due to changes in that part of the circuit which is essentially of copper is greatly minimized. Thus, if the copper part of the winding forms but 1/40 of the total resistance of the circuit, the temperature range through which the circuit may be carried with only 1% error in the current-per-volt is increased from 4 to 160 degrees.

Elimination of the inherent temperature error remains however a problem; and any form of compensation or correction which may be attempted requires considerable care in its design. If the series resistor could be made of a material having a suitable negative temperature coefficient, and then maintained at the same temperature as the copper winding, the resistance of the circuit could be made substantially constant. Not only is such a material commercially unavailable, but the difficulty of maintaining an absolutely uniform temperature within the instrument renders this method impracticable.

It will be seen that the increasing resistance with rise of temperature in the instrument tends to reduce the current-per-volt in the windings and thus weaken the inherent torque. Now, by a fortunate coincidence, the characteristics of certain materials available for control springs is such that a temperature increase tends to weaken the spring. It is possible, moreover, to bring the springs on an ordinary indicating instrument into reasonably close thermal association with the copper parts of the windings. In well-designed instruments these properties are utilized to the extent that for all ordinary temperature changes the sources of error are balanced and the actual error due to this cause rendered negligible.

In ammeters, where the resistance of the winding does not enter directly into the calibration of the instrument, this temperature compensation is not necessary; and it is customary to use control springs having a negligible temperature coefficient of elasticity.

There is sometimes used in conjunction with shunted ammeters a bridge circuit proposed by Campbell in England, wherein the terminals of the shunt are connected to opposite corners of a four-armed bridge network having arms alternately of temperature-sensitive and of zero temperature coefficient material* as shown in Fig. 46-1. Since some of the current is always diverted

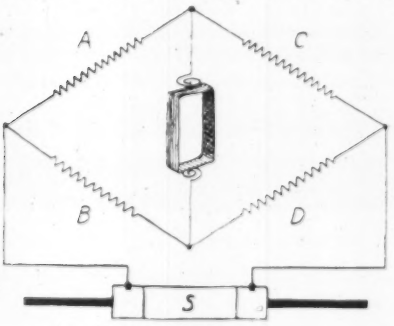

Fig. 46-1

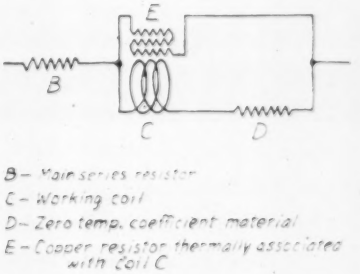

Fig. 46-2

from the movement of the instrument, this device is of inherently lower efficiency than a movement connected directly across the terminals of the shunt, but by properly proportioning the bridge arms it is possible to eliminate such errors as are likely to develop due to differences in shunt and instrument temperatures.

A somewhat similar scheme used by H. S. Baker for eliminating temperature errors in wattmeters and voltmeters is shown in Fig. 46-2. This compensation, which is particularly suited for instruments wherein it is not practicable to make use of temperature characteristics of the control springs, consists in varying the distribution of current in the potential circuit between the active windings and a shunt across the windings in response to temperature variations. In Fig. 46-2, C represents the copper coil or winding of the instrument. Wound in with the coil is a bifilar copper winding E in intimate thermal association with the coil, but having no inductive effect. In series with the coil C

*Edgecumbe & Ockenden. Industrial Electrical Measuring Instruments. Pitman Publishing Corp., 1933. Page 163.

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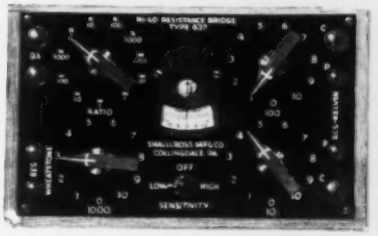

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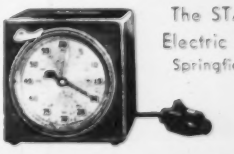

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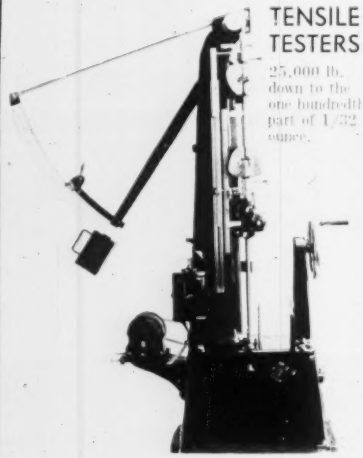

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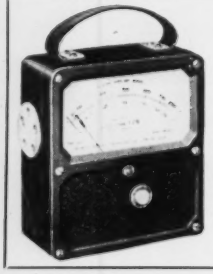

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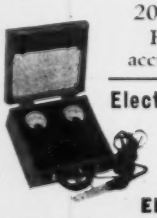

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is placed a resistor D of zero temperature coefficient material, and the winding E is connected in parallel with the combination of C and D. In series with the whole, across the circuit whose voltage enters into the measurement, is the usual resistor B of zero temperature coefficient material. By properly proportioning the resistance of the component elements of the network it is possible to maintain a high degree of constancy in the ratio between the current in the winding of the instrument and the circuit voltage over a wide range of temperatures.

Instruments whose operating principle depends upon the change in temperature of internal parts brought about by changes in the magnitude under measurement are generally made self-compensating, it being the custom to oppose an element which responds to temperature changes originating in the measured magnitude by another element of similar design responding only to temperature changes from other sources. The two opposed elements being exposed to the same disturbing effects, these effects are balanced out, and the ultimate deflection depends only on the measured magnitude.

(b) Mechanical Errors.

Under the head of mechanical errors may be considered scale errors and those due to friction and backlash in the moving parts. The first, due to the marking of the scale not being in agreement with the measured value, is likely to be present to some extent in almost any instrument. As long as this error does not change, and its value is known and recorded, a suitable correction may be applied, and it need not be considered an error.

Friction may exist in the bearings by reason of worn or damaged jewels or pivots, or it may be present at other points. Friction due to rubbing of the pointer on the scale or to small particles of foreign matter in the air gaps or damping chamber generally has the effect of making the indications so erratic as to call immediate attention to the trouble and to make the instrument useless until the trouble is removed. Friction in the bearings usually manifests itself in a sluggishness of action and a noticeable uncertainty of zero. Backlash is due primarily to loose fits in the working parts and sometimes is difficult to detect unless the instrument be checked against a standard, when this effect will become evident in a failure of the readings to agree when two checks are made, one going up the scale and the other down.

Errors due to backlash and to bearing friction may be materially reduced by a gentle tapping or vibration of the instrument while observations are being made; but since their causes are likely to be productive of more serious results they should be eliminated wherever possible.

Errors due to bent pointers are quickly detected (in most instruments) by a lack of parallelism between the indicator and the scale markings. Such errors should be rectified, not by readjusting the zero but by straightening the pointer.

(c) Electrical Defects

By "electrical defects" is meant such defects as may develop in the electrical circuits of the instrument subsequent to assembly and test. These are of a variety of kinds; they may take the nature of loose conductors, partial or complete short circuits or grounds, bad connections and open circuits.

Loose conductors are not likely to be found in well-built instruments, but cases are on record where a coil or a heavy lead carrying current has been insufficiently supported, permitting it to change its position under operating conditions. In such cases it is readily understood that no degree of permanent accuracy could be expected from the instrument in question.

Short circuits in operating coils are a fertile cause of trouble. The current coils in ammeters and wattmeters, either through mishandling or static discharge, sometimes develop short-circuited turns which may give rise to deceptive and elusive results. The natural tendency of a short-circuited turn, of course, is to weaken the operating torque, to which fault may be added a change in the proportionality of the scale. The short circuit may be of an intermittent nature, changing its performance with the slight expansion as the circuit of the instrument changes its temperature. Probably the most troublesome of all short circuits which can occur in an instrument is one in the moving coil of a voltmeter or wattmeter. Here the total resistance of the circuit is but little altered, while the directive force may change considerably and erratically. Such a defect demands attention from an expert instrument builder and frequently requires the installation of a complete new moving element.

The effect of grounds in the instrument circuits varies, of course, according to the point at which the ground occurs. In some instances, an accidental ground produces no effect until a second ground takes place, while in others all the symptoms of a partial or complete short circuit may be in evidence

An open circuit usually, though not always, manifests itself in a failure of the instrument to give a deflection. In some types of instruments the moving coil is paralleled by a shunt circuit, either for the purpose of adjustment or for reducing temperature or frequency errors; and, this circuit becoming open, there is a likelihood of the pointer receiving an abnormal deflection. Open circuits in the main series resistor of a wattmeter or voltmeter result in a failure to deflect, while shorted turns tend to increase the reading. Sometimes, due to poorly soldered joints or to corrosion, an abnormally high resistance contact will develop, with a resultant error and—if in a current circuit—local heating.

Precautions pertaining to shunts and leads were given in the article* on Ammeters and Voltmeters. When the shunt is separate from the instrument the leads are considered a part of the latter and should never be altered without recalibrating the instrument. Shunts should be carefully inspected for loose connections between terminal blocks and shunt leaves; such loose connections may introduce considerable errors—the existence of which might remain unsuspected.

These electrical defects can usually be detected only by observation of the instrument for erratic action and when detected usually require a careful and complete repair before the instrument can again be considered reliable for service.

(d) Spring Errors.

The basic causes of error due to characteristics of the control springs of instruments will be understood from an earlier article†, wherein are pointed out the essential features of springs in order that they may be adapted to use in the various types of instruments. Fatigue and aging of springs, manifesting itself in a "drift" of calibration, was a common characteristic of the older designs, and it was necessary to make allowance for such errors in any precision work which might be undertaken. Within the past few years phenomenal metallurgical advances‡ which have been made in spring design have rendered negligible any probable error from this source, so long as the springs are not subjected to mechanical or electrical abuse. When springs have become strained owing to unskillful manipulation or overheated by abnormal current flow or by injudicious soldering there may be introduced into the instrument errors which will be of considerable magnitude and erratic in their nature. "Kinked" springs will frequently manifest the fault by a sudden change in the calibration curve of the instrument at one point of the scale, this point generally being different on increasing from decreasing test values. In general the control springs of an instrument should be as nearly as possible mechanically perfect; and springs which have received any form of damage should be discarded and replaced by new units if accuracy of measurement is to be expected.

(e) Unbalancing.

Portable indicating instruments are usually intended to be used with the shaft in a vertical position. Unless the element is perfectly balanced and the bearings closely fitted, deviations from this position may affect the accuracy of the indications. If the element be out of balance, tilting the instrument will cause a change in the zero position. A perfectly balanced instrument should show the same zero no matter in what position it is placed. Errors due to unbalance may be made to disappear by leveling the instrument with the shaft truly vertical. If the fit of the bearings of the instrument is not snug there is a possibility of a certain degree of side-play in the movement, which will change with differing degrees of tilt. The operating torque of the instrument itself may also produce sufficient side-thrust to deflect the shaft from one side of the jewel to the other. In such cases there will be noted a sudden change of accuracy, due to the new position occupied by the movement in the field, as the critical point is passed, and this "kink" in the calibration curve will change its position with slight alterations in the degree of slope of the shaft. In the instance of portable polyphase wattmeters, where the directive force is derived in varying proportions from two elements on the one shaft, this condition may give rise to considerable errors even in well leveled instruments. The only cure for this trouble lies in a careful fitting of the jewels, so that side play is minimized.

Switchboard instruments of the horizontal-shaft form are less subject to unbalancing errors, but the foregoing remarks on looseness of pivots and jewels are to some extent applicable**.

*"*Instruments*, May 1934, pages 90-96.
†*Instruments*, May 1934, pages 95-96.
‡R. W. Carson, Bibliography on Inelastic Behavior of Springs. Pamphlet published by The Instruments Publishing Co., Pittsburgh. Contains 112 references, each briefly abstracted.
**F. S. Stuckney, The Factor of Merit of Horizontal-shaft Electrical Indicating Instruments. *Instruments*, May 1935, pages 112-114.

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